#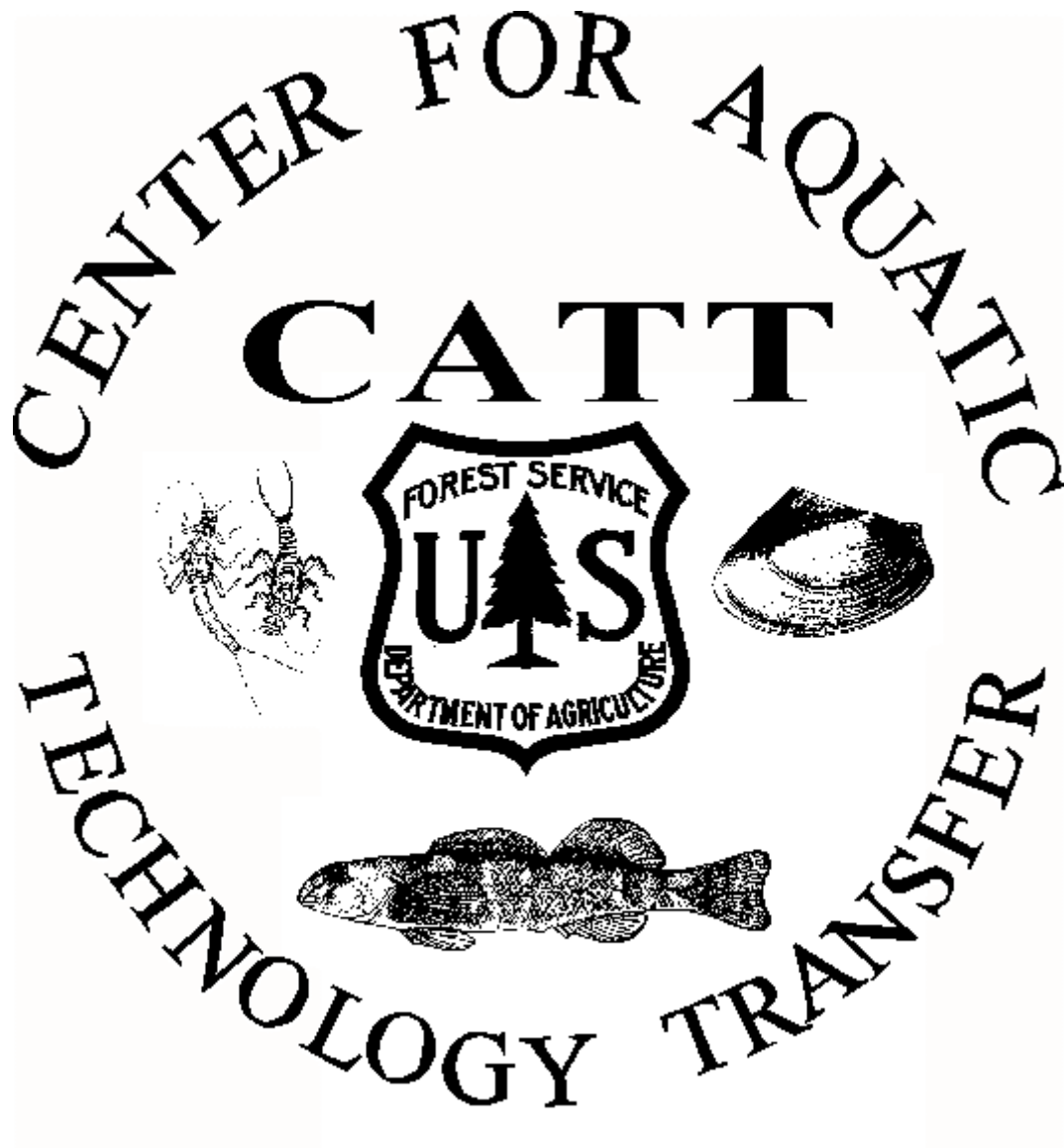 Current Condition of Rio Icacos and Rio Espiritu Santo, and Assessment of the Basinwide Visual Estimation Technique (BVET) Fish Survey for the Caribbean National Forest



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# Current Condition of Rio Icacos and Rio Espiritu Santo, and Assessment of the Basinwide Visual Estimation Technique (BVET) Fish Survey for the Caribbean National Forest

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# Introduction

In the summer of 1996, we made a site visit to the Caribbean National Forest (CNF) to provide training and on-the-ground experience with the basinwide visual estimation technique (BVET) (Leftwich and Dolloff 1997). Personnel completed a weeklong training-survey, which provided both training and practical field experience surveying habitat and aquatic fauna in CNF streams. Results from the training-surveys were limited because multiple, inexperienced individuals performed the surveys on a relatively short reach of stream. We gathered enough information to conclude that the BVET habitat survey could successfully be used to inventory stream habitat in the CNF. Streams in the CNF were morphologically similar to streams in the Appalachian Mountains of the eastern United States where BVET habitat surveys have been successfully performed for years. We also concluded that traditional BVET fish survey techniques might not be adequate for assessing aquatic fauna in CNF streams. Major elements of the fauna, which is dominated by shrimp and crabs, were not as susceptible to electrofishing as fish species for which the BVET was originally developed.

In summer 2000 we further assessed the use of BVET habitat and fish surveys by surveying Rio Gurabo (Roghair and Whalen 2000). As during our initial visit, the BVET habitat survey was successfully completed, however the fish survey was not. Our divers could count the species of shrimp and crab but we were unable to calibrate the diver counts using electrofishing. Without calibrated estimates we could not estimate the size of the shrimp population.

This report presents the results of BVET surveys performed during two trips to the CNF in 2001. In February we performed a BVET habitat survey on Rio Icacos. Distribution and relative abundance data for shrimp, crab, and fish species were collected through diver counts. In addition, we assessed the effectiveness of several methods that may be used to estimate population sizes, including three-pass electrofishing, bounded diver counts, hand netting, and trapping. In July we returned to perform diver counts and a BVET habitat survey on Rio Espiritu Santo.

# Methods

## Study Area

Rio Icacos originates within the CNF at an elevation just over 650 m, southeast of the peak of Mt. Britton and flows for approximately 5.5 km before it joins with Rio Cubuy to form Rio Blanco. Between February 27 and March 5, 2001, we performed a BVET habitat survey and a diver survey on Rio Icacos starting its confluence with Rio Cubuy and ending at the upstream extent of the river (Figure 2). The study section consisted of a mixture of high gradient cascades and waterfalls in the lower elevations and a several kilometer long, low gradient section in the upper reaches of the stream. The aquatic fauna in the

study section consisted of several shrimp species, one crab species, and one fish species. The riparian area consisted of tropical rainforest with a dense understory.

Quebrada Jimenez is a major tributary in the Rio Espiritu Santo drainage. It originates within the CNF at an elevation above 700 m and flows north for approximately 3 km before exiting the CNF. On July 6, 2001 we used several methods to attempt to estimate shrimp and fish population sizes within two pools in Quebrada Jimenez. The pools contained several species of shrimp and one species of fish.

Rio Espiritu Santo originates southwest of Mt. Britton at an elevation of nearly 750 m and flows northwest for approximately 9 km, to an elevation of less than 100 m before it exits the CNF. On March 7, 2001 we used several methods to attempt to estimate the shrimp and fish populations in a pool near the Forest boundary (Figure 2). Between July 9 and July 20, 2001, we performed a BVET habitat survey and a diver survey on Rio Espiritu Santo starting at the Forest boundary near the girl scout camp and ending approximately 8.5 km upstream (Figure 2). The downstream end of the study section was low to moderate gradient with large pools and long riffles. The middle section consisted of a mixture of high gradient cascades, plunge pools, and waterfalls, and the upper elevations consisted of long pools and runs and short, low gradient riffles. The aquatic fauna in the study section consisted of several shrimp species, one crab species, and four fish species. The riparian area consisted of tropical rainforest with a dense understory.

**Habitat**

We used standard BVET habitat survey protocols to estimate pool and riffle surface area and the total surface area of the study section (Hankin and Reeves 1988, Dolloff et al. 1993). Habitat was stratified into similar groups based on naturally occurring habitat units including pools (areas in the stream with concave bottom profile, less than average gradient, greater than average depth, and smooth water surface), and riffles (areas in the stream with convex bottom profile, greater than average gradient, less than average depth, and turbulent water surface). Glides (areas in the stream similar to pools, but with average depth and flat bottom profile) were identified during the survey but were grouped with pools for data analysis. Runs (areas in the stream similar to riffles but with average depth, less turbulent flow, and flat bottom profile) and cascades (areas in the stream with > 12% gradient, high velocity, and exposed bedrock or boulders) were grouped with riffles for data analysis.

Habitat was classified and inventoried by a two-person crew using two-stage visual estimation techniques. One crew member identified all habitat units within the surveyed stream reach by type (pool, riffle, etc.), measured each unit's length, visually estimated each unit's wetted channel width, dominant and subdominant substrata particle size, and average and maximum depths. The second crew member classified and inventoried the amount of large woody debris (LWD) within the active stream channel for each habitat unit and recorded data. Unit lengths were measured to the nearest 0.1 m with a hipchain.

Substrate particle size (modified Wentworth scale) was visually estimated. The size class that covered the greatest amount of surface area in a given habitat unit was declared the dominant substrate. The subdominant substrate covered the second greatest amount of surface area. Depths were measured to the nearest 1.0 cm by taking depth measurements with a graduated staff at various places across the channel profile within each habitat unit.

Wetted channel width estimates were calibrated by measuring the widths of approximately 10% of the pools and riffles in the surveyed reach. The first unit of each habitat type selected for paired estimates and measurements of width was determined randomly. Additional paired sampling units were selected systematically (in this case every 10th habitat unit was selected). In pools that were selected for width measurement we also measured canopy closure and estimated instream overhead cover and substrate embeddedness. In riffles selected for width measurements we measured the bankfull channel width, canopy closure, and gradient, and estimated instream overhead cover and substrate embeddedness. Width measurements were made to the nearest 0.1 m with a tape measure. We defined instream overhead cover as rock, wood, or undercut bank within the wetted channel that would provide sufficient cover to hide a 15 cm long object. We visually estimated linear meters of available cover for each category (rock, wood, undercut bank). We visually estimated the percent of the total substrate surface area that was embedded. We considered substrate to be embedded if interstitial spaces around large substrate particles were filled by smaller substrate particles. Canopy closure was measured with a convex spherical densiometer while standing in the center of the habitat unit. Gradient was measured with a clinometer from the upstream to the downstream extent of riffles.

Total surface area of pools and riffles was calculated using an Excel spreadsheet (Dolloff et al. 1993). Maximum and average depths, dominant and subdominant substrates, canopy closure, embeddedness, gradient, and instream cover, and LWD data were summarized using Excel spreadsheets and SigmaPlot graphing software.

**Aquatic Fauna**

We inventoried aquatic fauna in Rio Icacos and Rio Espititu Santo by performing diver counts in approximately 20% of pools and riffles. One to three divers were used depending on habitat unit size. The diver(s) entered the selected habitat units and proceeded slowly upstream while searching for and counting all encountered individuals. It was often necessary to turn over substrate particles to count hidden shrimp, crab, and fish. Diver counts were used to examine the distribution and relative abundance of each species.

**Population Estimation Experiments**

Based on our past experiences we suspected that 3-pass electrofishing was not providing us with reliable depletions upon which we could base population estimates (Leftwich and Dolloff 1997, Roghair

and Whalen 2000).  In 2001 we further assessed the effectiveness of three-pass electrofishing and searched for an alternative technique.  We performed multiple pass diving counts and 3-pass depletions on two Quebrada Jimenez pools and one Rio Espititu Santo pool.  We also briefly experimented with hand netting and trapping for estimating population abundance.

On each pool, we began by performing a three-pass diver count (bounded count), then performed a three-pass electrofishing depletion, and finished with a single-pass diver count.  Blocknets were placed at the upstream and downstream end of each pool where natural barriers would not prevent species from leaving the unit.  A single diver entered the downstream end of the pool and moved upstream, methodically searching for and counting each species encountered.  The pool was allowed to settle for 5-10 minutes between each pass.  After completing the bounded count we allowed the pool to settle for 5-10 minutes and then began three-pass depletion electrofishing.  Each pass was made using one Smith-Root DC, battery powered backpack electrofishing unit set to 200-300 V.  Shrimp, fish, and crabs were captured and removed during each successive pass by two dipnetters.  The estimated number of each species found in the pools was calculated for bounded counts and three-pass depletion electrofishing using methods outlined in Hicks and Watson (1985) and Kwak (1991), respectively.

We also briefly experimented with handnetting and trapping techniques.  We attempted to capture species of shrimp while diving in pools by using an aquarium dipnet.  We attempted to trap shrimp and crabs in wire mesh minnow traps baited with items ranging from chicken bones and cat food to pieces of fruit.

## Results

**Habitat**

*Rio Icacos*

We surveyed habitat in 5.5 km of the mainstem of Rio Icacos and identified 148 pools, 30 glides, 66 riffles, 50 cascades, and 17 runs within the stream.  Dams were encountered at two locations (Figure 1).  Dam 1 was located at survey meter 1340 and was used to supply water to a hydroelectric facility further down the mountain.  The dam was approximately 10 m high and created a 6700 $m^2$ pool.  Dam 2 was located at survey meter 3100 and was used to pool water for a stream gauging station.  The dam was 1 – 2 m high and created a 1000 $m^2$ pool.  We were forced to skip a dangerous section of the stream downstream of the dam 2 location.  Huge boulders completely filled the channel and hid the stream, making passage extremely dangerous.  The skipped section was not reflected in any of our figures because we did not have an estimate of its length.  It was likely less than 500 m long.

Visual estimates of habitat area were paired with measured habitat area for 15 (8.4%) pools (includes pools and glides) and 13 (9.7%) riffles (includes riffles, runs, and cascades). We estimated that the reach contained 64% pool habitat (22884±1160 $m^2$) and 36% riffle habitat (12732±1053 $m^2$) (Figure

3).  Total area was estimated for pools and riffles using correction factors of 1.20 and 1.00, respectively. The wetted stream width ranged from 2 m to 12 m with an average of 5 m and the bankfull channel width ranged from 4 m to 35 m with an average of 19 m (Figure 4).

Maximum pool depths in Rio Icacos ranged from 25 cm to 280 cm, with a mean of 99 cm and maximum riffle depths ranged from 10 cm to 210 cm, with a mean of 70 cm (Figure 5).  Average pool depths ranged from 10 cm to 210 cm, with a mean of 64 cm and average riffle depths ranged from 3 cm to 95 cm, with a mean of 33 cm.  Riffle crest depths ranged from 3 cm to 95 cm and averaged 33 cm.

The most frequently encountered substrate types in Rio Icacos were boulder and sand.  Boulder was the dominant substrate in 40% of pools and 54% of riffles (Figure 6).  Sand was the dominant substrate in 37% of pools and 9% of riffles.  Sand and small gravel comprised the majority of subdominant substrates in pools and cobble comprised the majority in riffles.

Rio Icacos contained 127 pieces of LWD per km, of which the majority was >5 m long, 5-10 cm in diameter (Figure 7).  There was a distinct lack of LWD throughout the first kilometer of the stream reach, however LWD was scattered evenly throughout the remainder of the stream (Figure 8).

Undercut banks and LWD provided very little potential instream cover in Rio Icacos.  Rock cover was observed throughout the first 3 km of Rio Icacos , but was nearly absent in the upstream reaches (Figure 9)

Canopy closure ranged from near zero to 100%.  Copy closure increased noticeably from downstream to upstream reaches (Figure 10).

Embeddedness showed similar trends to canopy closure, increasing dramatically in the upstream reaches of the stream (Figure 10).

Gradient was not measured in Rio Icacos.

*Rio Espiritu Santo*

We surveyed habitat in 8.5 km of the mainstem of Rio Espiritu Santo and identified 292 pools, 7 glides, 133 riffles, 68 cascades, and 16 runs within the stream.  We encountered one dam at survey meter 4400 (Figure 2).  The dam was 2.5 m high, created a 450 m$^2$ pool and was used to supply water to a water intake pipe that was installed in 2000 (Bruce Drapeau, pers. comm.)

Visual estimates of habitat area were paired with measured habitat area for 24 (8.0%) pools (includes pools and glides) and 17 (7.8%) riffles (includes riffles, runs, and cascades). We estimated that the reach contained 53% pool habitat (38747±2961 m$^2$) and 47% riffle habitat (34842±4717 m$^2$) (Figure 11).  Total area was estimated for pools and riffles using correction factors of 1.06 and 1.13, respectively. The wetted stream width ranged from 2 m to 22 m with an average of 10 m and the bankfull channel width ranged from 4 m to 45 m with an average of 23 m (Figure 12).

Maximum pool depths in Rio Espiritu Santo ranged from 10 cm to 500 cm, with a mean of 120 cm and maximum riffle depths ranged from 15 cm to 195 cm, with a mean of 70 cm (Figure 13). Average pool depths ranged from 15 cm to 350 cm, with a mean of 84 cm and average riffle depths ranged from 5 cm to 110 cm, with a mean of 41 cm. Riffle crest depths ranged from 5 cm to 100 cm and averaged 27 cm.

The most frequently encountered substrate types in Rio Espiritu Santo were boulder, bedrock, sand, and cobble. Boulder or bedrock was the dominant substrate in 82% of pools and 96% of riffles (Figure 14). Sand was the dominant substrate in 13% of pools. Cobble or boulder was the subdominant substrate in 77% of pools and 85% of riffles. All other substrate types were present but were relatively scarce.

Rio Espiritu Santo contained 114 pieces of LWD per km, of which the majority was >5 m long, <50 cm in diameter (Figure 15). LWD was distributed in low amounts throughout the stream with occasional log jams in the more upstream reaches (Figure 16).

Undercut banks and LWD provided very little potential instream cover in Rio Espiritu Santo. Rock cover was observed throughout the stream reach (Figure 17). Cover was not estimated upstream of stream meter 7000 due to time constraints. Wood cover likely increased and rock cover decreased in this section as sand became the dominant substrate and debris jams increased (Craig Roghair pers. obs.)

Canopy closure ranged from near zero to nearly 100%. Copy closure increased from downstream to upstream but did not close completely for any major length of stream (Figure 18). Canopy closure was not measured upstream of meter 7000 due to time constraints. Canopy closure increased to near 100% by meter 8500 (Craig Roghair pers. obs.).

Embeddedness was greatest in pools in the furthest downstream and furthest upstream reaches (Figure 18). Embeddedness was not estimated past stream meter 7000 due to time constraints. The units upstream of meter 7000 were generally highly embedded by sand (Craig Roghair pers. obs.).

Gradient was low at the downstream end of the stream reach and increased dramatically in the middle reaches (Figure 18). In the several kilometer long middle reach, gradients > 20% were common and many cascades and several waterfalls were encountered. Gradient was not measured past meter 7000 due to time constraints. The stream gradient was typically < 2% upstream of meter 7000 with the exception of a short high gradient reach starting at a major tributary near meter 7800.

**Aquatic Fauna**

*Rio Icacos*

We sampled 34 (19%) pools and 24 (18%) riffles in the 5.5 km stream reach. Habitat units were typically moderate in size, requiring up to two divers in the downstream reaches and a single diver in the upstream reaches. In total, we encountered six identifiable species of shrimp (*Xiphocaris elongata*, *Atya*

*lanipes*, *Micratya poeyi*, *Macrobrachium faustinum*, *Macrobrachium heterchirus*, and *Macrobrachium carcinus*), one species of crab (*Epilobocera sinuatifrons*), and one species of fish (*Sicydium plumeiri*). Two species of shrimp (*Atya scabra* and *Atya inocous*) could not be distinguished by divers and were lumped into an *Atya* spp. category.

X. *elongata* was the most widespread and commonly encountered species (Figure 19). *A. lanipes* was not as widespread as *X. elongata* but had high population densities where encountered. All other species were found in much lower numbers (Figures 20 & 21). *X. elongata, A. lanipes*, and *E. sinuatifrons* all displayed highest densities in the middle section of the reach. *M. faustinum, M. heterochirus, M. carcinus, M. poeyi, E. sinuatifrons*, and *S. plumieri*, were found scattered throughout the lower and middle sections of the reach but were not typically encountered upstream of meter 3000.

*Rio Espiritu Santo*

We sampled 51 (17%) pools and 38 (18%) riffles in the 7.0 km stream reach. Habitat units were typically large in size, requiring up to three divers in the downstream reaches and a single diver in the far upstream reaches. In total, we encountered seven identifiable species of shrimp (*Xiphocaris elongata*, *Atya lanipes*, *Micratya poeyi*, *Macrobrachium faustinum*, *Macrobrachium heterchirus*, *Macrobrachium crenulatum*, and *Macrobrachium carcinus*), one species of crab (*Epilobocera sinuatifrons*), and four species of fish (*Sicydium plumeiri, Awaous banana, Agonostomus monticola, Poecilia reticulata*). One species of fish (*Anguilla rostrata*) was observed just downstream of the Forest boundary and was observed in the study reach during the population estimation experiments. Two species of shrimp (*Atya scabra* and *Atya inocous*) could not be distinguished by divers and were lumped into an *Atya* spp. category. Immature *Macrobrachium* species could not be distinguished by divers and were lumped in to a *Macrobrachium* spp. category.

S. *plumeiri* and X. *elongata* were the most widespread and commonly encountered species (Figure 22). *A. lanipes* was not as widespread as *X. elongata* or *S. plumieri* but had higher population densities where encountered. All other species were found in much lower numbers (Figures 23, 24, 25, & 26). *X. elongata* and *A. lanipes* displayed highest densities in the middle and upper sections of the reach. *M. heterochirus* and *M. carcinus* were found scattered throughout most of the reach in low densities (Figures 23 & 24). *M. faustinum* was found in moderate density downstream of meter 3000. *M. crenulatum* was found in low density upstream of meter 3000. Immature *Macrobrachium* were encountered in moderate densities downstream of meter 3000 and were only sporadically encountered upstream (Figure 24). *X. elongata, A. lanipes, E. sinuatifrons*, and *S. plumieri* were all observed to the upper extent of the habitat survey (Craig Roghair pers. obs.).

**Population Estimation Experiments**

No consistent results were obtained using bounded counts or three-pass depletion electrofishing to estimate aquatic fauna population size (Table 1).  Bounded counts were closest to three-pass depletion estimates for *X. elongata*.  *A. lanipes* population estimates were much lower using bounded counts than three-pass depletion. Three-pass depletion estimates could not be calculated for several of the species because valid depletions (i.e. fewer fish captured in each successive pass) were not obtained.  Post-electrofishing diver surveys indicated that many individuals of several species had eluded capture.

Diving passes took a median of 20 minutes each on Quebrada Jimenez and 24 minutes each on Rio Espiritu Santo.  Electrofishing passes on Rio Espiritu Santo took approximately 24 minutes each.  We did not record electrofishing times on Quebrada Jimenez.  Allowing for time between passes both methods took well over 1 hour per pool.

Handnetting and trapping were not effective for capturing the majority of species. *X. elongata* could be captured by handnetting, but not efficiently.  Most other species made extensive use of interstitial spaces, making capture nearly impossible (C. Roghair, pers. obs.).  Baited traps attracted *X. elongata* and several species of *Macrobrachium*, however other species did not appear to be attracted.

## Discussion

**Habitat**

*Rio Icacos*

The combined effect of high channel gradient and high flow events was evident in the lower section of Rio Icacos. In this section, substrates were dominated by boulder and bedrock, there was a lack of LWD (especially in the wetted channel), the tree canopy was open, instream cover was dominated by rock, and substrates were not typically embedded. In the middle section of the survey, channel gradient decreased and became very low upstream of survey meter 3000. Decreased drainage area combined with lower gradient dampens the effect of high flows in these sections resulting in a change in habitat conditions. In these sections smaller substrates such as sand became dominant, there was an increase in the amount of LWD in the stream channel, bank vegetation shaded the stream channel, and rock cover was lost as substrates became embedded.

A particularly interesting portion of the stream was located downstream of dam 2, near survey meter 3000. It appeared that landslides had dropped house sized boulders into the stream channel in this area, completely hiding the stream in some sections and creating 'caves' where boulders fell over bedrock gorges in others. Unfortunately, this area was also extremely dangerous to pass.

*Rio Espiritu Santo*

Rio Espiritu Santo began as a low to moderate gradient stream, but by survey meter 2500 had increased in gradient dramatically. The stream remained mostly high gradient until meter 7000, where it became meandering and low gradient, much like the upper reach of Rio Icacos. Although Rio Espiritu Santo was generally wider and contained deeper pools, its habitat variables responded similarly to changes in gradient as those in Rio Icacos. Boulder substrates dominated high gradient areas, whereas sand dominated lower gradient areas. The amount of LWD was notably low in the stream, however several small log/debris jams were encountered in the low gradient upper section.

*Summary*

In total, we surveyed 14 km of habitat in Rio Icacos and Rio Espiritu Santo. The surveys assessed the amount of pool and riffle area, habitat unit depths, channel size, substrate, LWD, cover, canopy closure, substrate embeddedness, and gradient. As more streams in the CNF are surveyed comparisons between streams may be made, and as streams are resurveyed changes in individual streams can be observed. This seems particularly useful in the CNF where flash flooding and hurricanes have the potential to bring rapid changes to stream habitat.

The CNF may want to consider adding some variables to their habitat surveys and removing others. For example, adding an altimeter (elevation) reading at locations where paired samples are taken would be useful for locating map positions and may provide data useful for describing shrimp

distributions.  The cover estimate needs to be modified, or possibly removed from the survey altogether. The cover estimation technique was developed to describe the amount of overhead cover provided to fish species of the southeastern US.  It provides an estimate of the amount of overhead cover for a 15 cm fish. Most of the shrimp and many of the fish in the CNF are less than 15 cm in length and use small interstitial spaces for cover.  Substrate embeddedness is probably a useful surrogate for the amount of cover available to shrimp, crab, and fish species in the CNF.

**Aquatic Fauna**

*Rio Icacos and Rio Espiritu Santo*

Although more shrimp species were encountered in Rio Espiritu Santo, we found similar trends between the streams in the distribution of several shrimp species.  In both streams *Macrobrachium* were absent from the upper (low gradient, sand substrate) reaches, likely due to a lack of interstitial spaces for cover during the day.  *X. elongata* and *A. lanipes* were observed in the low gradient, sandy reaches but were found in the highest densities in the middle reaches of both surveyed sections. The density of *A. lanipes* was so high in some Rio Icacos pools that divers could pick up several at a time by sweeping their hands through the water.  Shrimp fecal material often covered the bottom of pools in these areas.  Despite the existence of extremely high gradient cascades, waterfalls, and dams, shrimp were found to the upper extent of both surveys.  Longitudinal changes in the abundance of these species is likely less related to movement barriers than to changes in habitat conditions within the stream.

*E. sinuatifrons* (crabs) were found in low densities in both streams.  We more frequently observed dead crabs or pieces of crab shell on rocks while hiking than we did live crabs while diving.

*S. plumieri* were found in both streams, however their density and distribution varied markedly. We found this goby species throughout Rio Espiritu Santo in relatively high densities, whereas it was limited to the lower 2500 m of the Rio Icacos survey.  The species was not found upstream of the area where large boulders covered the stream channel in Rio Icacos.  *S. plumieri* was the only fish species observed in Rio Icacos.  Other fish species, such as *A. rostrata, A. monticola*, and *A. banana* that were found in Rio Espiritu Santo were not present in Rio Icacos.  These species were only observed in the lower elevation areas of Rio Espiritu Santo.  *P. reticulata* were found only in a short reach of Rio Espiritu Santo, just upstream of the Highway 186 bridge.  CNF personnel suspected that *P. reticulata* were introduced from an aquarium.

**Population Estimation Experiments**

The bounded counts and electrofishing depletions were performed by individuals who have years of experience using diving and electrofishing methods on a variety of habitats and species.  This experience notwithstanding, both methods took long amounts of time and results between the methods were inconsistent.  Problems also arose during data analysis. Estimates for three-pass depletions could not

be performed for several species because valid depletions (i.e. fewer fish captured in each successive pass) were not obtained. This frequently occurred for species such as *Macrobrachium*, which are often found in low densities (e.g. fewer than 5 individuals per unit). Low population density also creates problems for interpreting bounded count results. Hicks and Watson (1985) demonstrated that when counts total less than 7 individuals, population estimates obtained from bounded counts are unreliable.

Given these results and discussions with other biologists who have worked in the CNF, it may not be feasible to obtain statistically valid population estimates (K. Leftwich and E. Garcia, pers. comm.). Instead, we recommend that the CNF obtain relative abundance data. These data may be collected using a variety of techniques including diver surveys, electrofishing surveys, trapping or a combination of the techniques. Based on our experiences, diver surveys appear to provide the most efficient means by which to collect relative abundance data for a wide range of species. However, past studies have reported success using electrofishing techniques (Fievet et al. 1996, E. Garcia, pers. comm.) and baited traps (Covich et al. 1996, Pyron et al. 1999) to obtain relative abundance data.

Each technique has benefits and drawbacks. Diving or trapping may be more effective under certain conditions, such as in deep water, whereas electrofishing may be more effective for sampling shallow riffle areas where diving and trapping are difficult. For example, we captured 12 *M. poeyi* while electrofishing Rio Espiritu Santo, but observed none while diving (Table 1). *M. poeyi* is a small species that typically occupies fast, shallow water areas that are difficult to dive. Further, the vulnerability of certain species or individuals may vary between methods. For example, we observed over 100 *S. plumieri* while diving a pool in Rio Espiritu Santo, but only captured two while electrofishing the same pool (Table 1). Baited traps have been shown to favor large males when used for tapping crayfish species (Rabeni et al 1997). In addition, size (length and weight) data can only be collected during electrofishing or trapping surveys. We recommend development of a standard protocol to allow for comparisons among streams and across time.

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Table 1.  Results of population estimation experiments on Quebrada Jimenez and Rio Espiritu Santo, Caribbean National Forest.  Bounded count is three-pass diver counts; N (population estimate) calculated as in Hicks and Watson (1985).  Three-pass depletion is depletion electrofishing; N calculated as in Kwak (1991). Post-shock dive is a single-pass diver count made following three-pass electrofishing depletion. Asterisk indicates that population estimate could not be made because of invalid depletion. n/a indicates that species could be identified upon capture.

| | Bounded Counts | | | | Three-Pass Depletion | | | | | Post-Shock Dive |
|---|---|---|---|---|---|---|---|---|---|---|
| Q. Jimenez, Pool 1 | 1 | 2 | 3 | N | 1 | 2 | 3 | Total | N | Count |
| *X. elongata* | 105 | 170 | 105 | 235 | 69 | 38 | 36 | 143 | 219 | 79 |
| *A. lanipes* | 121 | 158 | 115 | 195 | 103 | 102 | 87 | 292 | 1335 | 62 |
| *M. carcinus* | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | * | 0 |
| *M. crenulatum* | 2 | 3 | 1 | 4 | 0 | 0 | 0 | 0 | * | 0 |
| *M. faustinum* | 1 | 0 | 0 | 2 | 1 | 1 | 0 | 2 | 2 | 0 |
| *Macrobrachium* spp. | 4 | 3 | 1 | 5 | n/a | n/a | n/a | n/a | n/a | 0 |
| *E. sinuatifrons* | 0 | 1 | 0 | 2 | 0 | 1 | 0 | 1 | * | 3 |
| *S. plumieri* | 24 | 42 | 30 | 54 | 0 | 0 | 0 | 0 | * | 8 |
| **Q. Jimenez, Pool 2** | | | | | | | | | | |
| *X. elongata* | 185 | 97 | 129 | 241 | 63 | 51 | 36 | 150 | 268 | 39 |
| *A. lanipes* | 102 | 64 | 113 | 124 | 123 | 113 | 58 | 294 | 461 | 23 |
| *M. carcinus* | 3 | 3 | 6 | 9 | 0 | 0 | 0 | 0 | * | 0 |
| *M. crenulatum* | 7 | 3 | 3 | 11 | 0 | 0 | 0 | 0 | * | 0 |
| *M. faustinum* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | * | 0 |
| *Macrobrachium* spp. | 0 | 1 | 0 | 2 | n/a | n/a | n/a | n/a | n/a | 0 |
| *E. sinuatifrons* | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | * | 0 |
| *S. plumieri* | 7 | 11 | 7 | 15 | 0 | 0 | 0 | 0 | * | 2 |
| **R. Espiritu Santo, Pool 1** | | | | | | | | | | |
| *X. elongata* | 136 | 127 | 114 | 145 | 110 | 66 | 55 | 231 | 347 | 28 |
| *Atya* spp. | 5 | 1 | 2 | 8 | 0 | 2 | 0 | 2 | * | 0 |
| *M. carcinus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | * | 0 |
| *M. crenulatum* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | * | 0 |
| *M. faustinum* | 2 | 2 | 13 | 24 | 0 | 0 | 5 | 5 | 0 | 3 |
| *M. heterochirus* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 |
| *Macrobrachium* spp. | 42 | 52 | 42 | 62 | 15 | 14 | 5 | 34 | 46 | 36 |
| *M. poeyi* | 0 | 0 | 0 | 0 | 7 | 1 | 4 | 12 | 18 | 5 |
| *E. sinuatifrons* | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | * | 2 |
| *S. plumieri* | 167 | 141 | 125 | 193 | 0 | 0 | 2 | 2 | * | 46 |
| *A. monticola* | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 2 | 2 | 1 |
| *A. rostrata* | 1 | 2 | 0 | 3 | 0 | 0 | 0 | 0 | * | 0 |
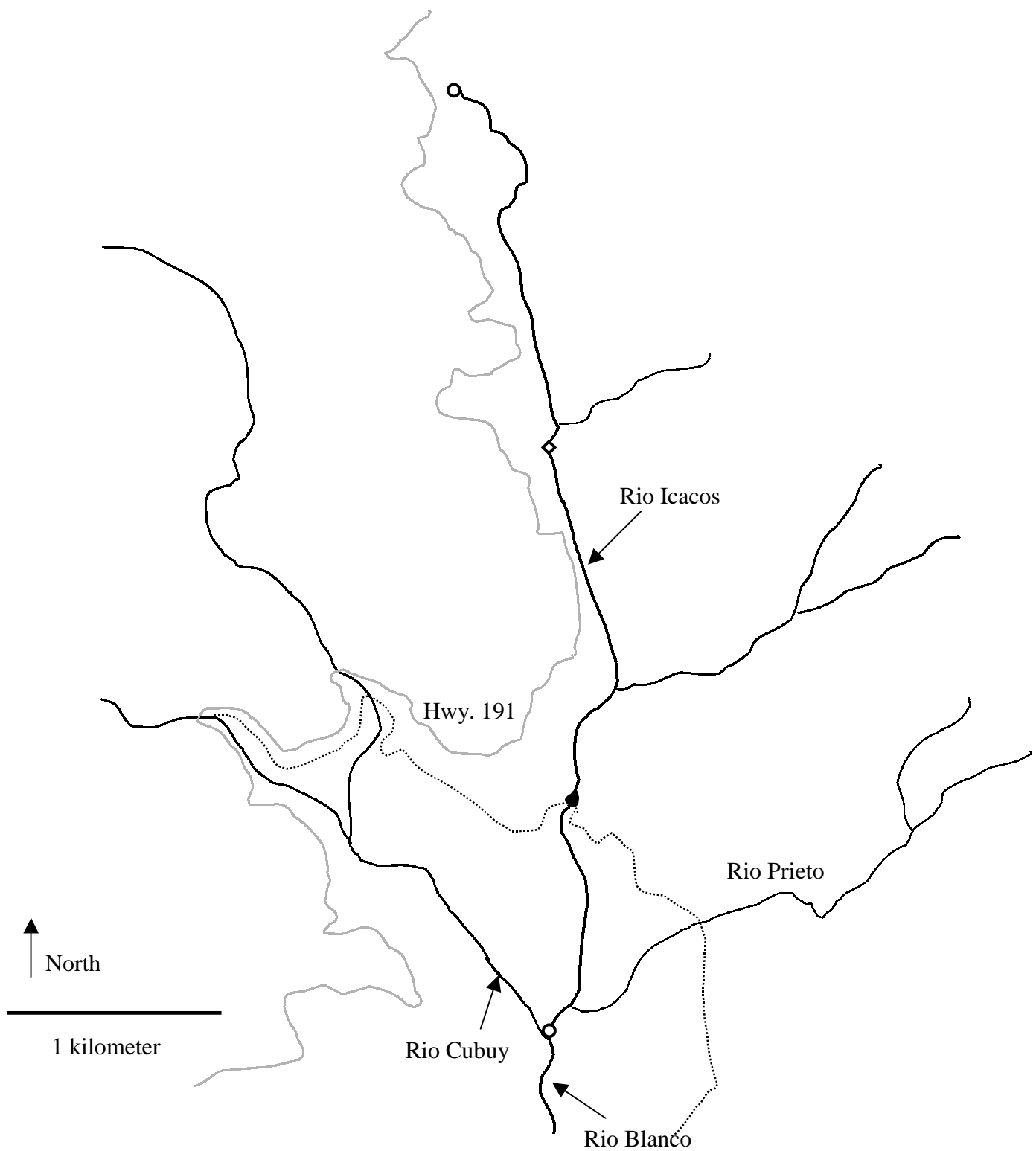
Figure 1. Study section of Rio Icacos. The open circles indicate starting and ending points of survey. The dotted line represents the water intake pipe for a hydroelectric facility. The open diamond indicates location of dam 2 (see text for description). Dam 1 was located where the pipeline crosses Rio Icacos. The grey line represents highway 191, note that portions of this road are obliterated from landslides.
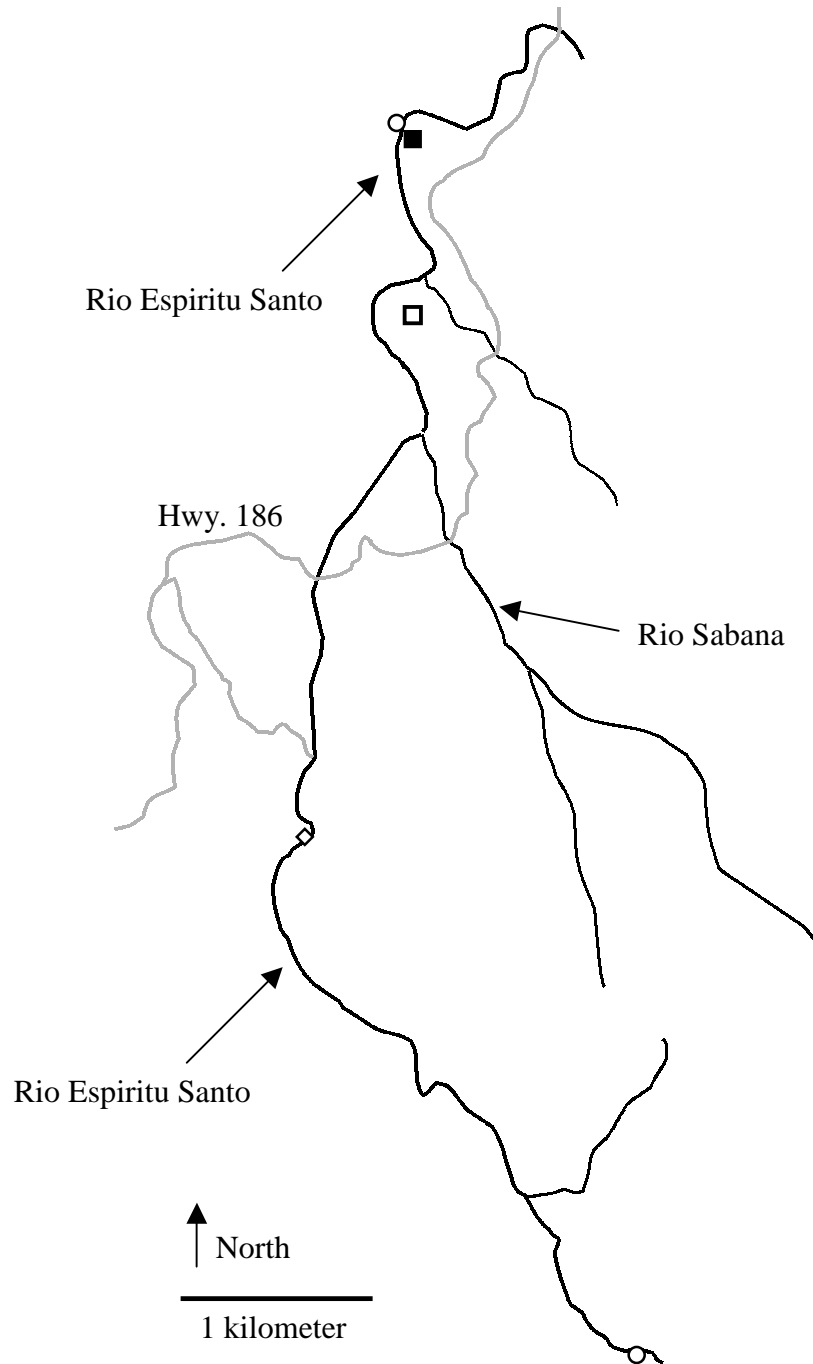
Figure 2. Study section of Rio Espiritu Santo. The open circles represent the starting and ending points of the survey. The open diamond indicates the location of a water intake structure and dam. The closed and open squares represent a Girl Scout camp and abandoned Job Corp camp, respectively. The grey lines represent highway 186 and an unpaved, gated Forest Service road.
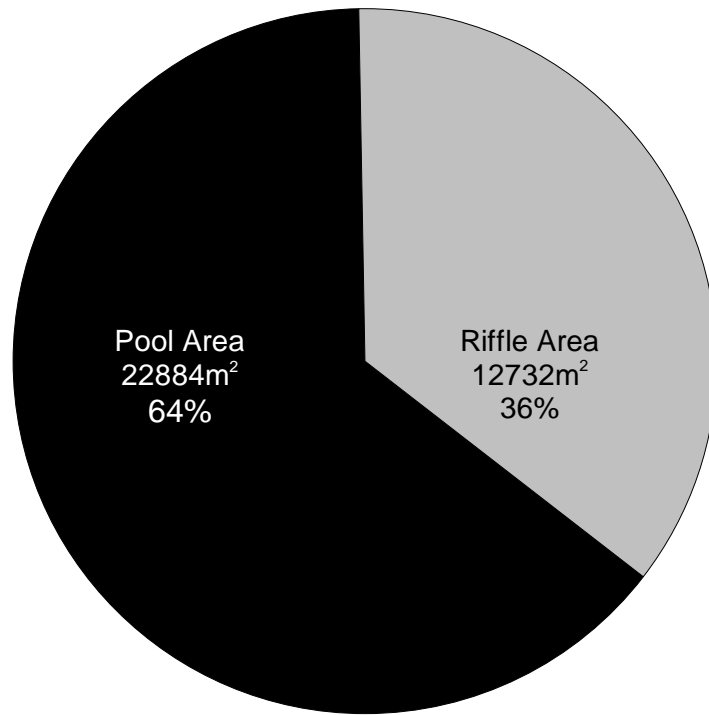
Figure 3. Estimated area of Rio Icacos in pools and riffles as calculated using BVET techniques, February 2001.
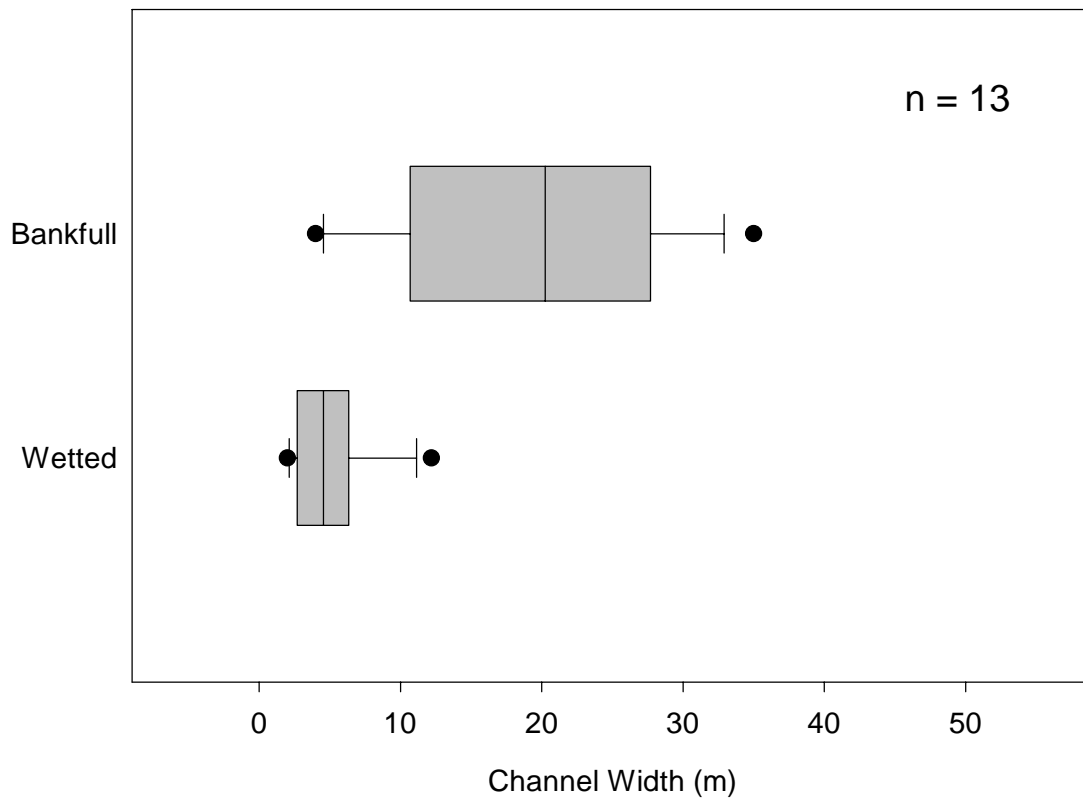


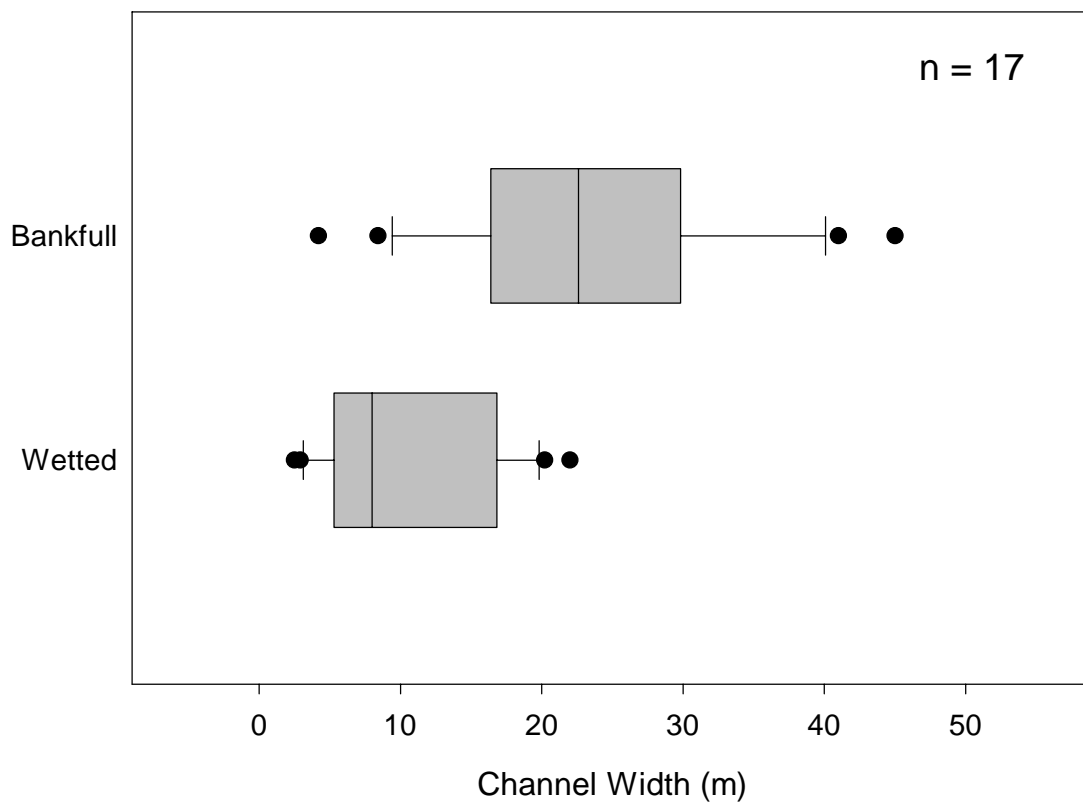Figure 4. Bankfull and wetted channel widths for Rio Icacos, February 2001. The left and right of the boxes represent the 25th and 75th percentiles, the bar in the center of the box represents the median, whiskers represent the 10th and 90th percentiles, and closed circles represent the entire range of the data.
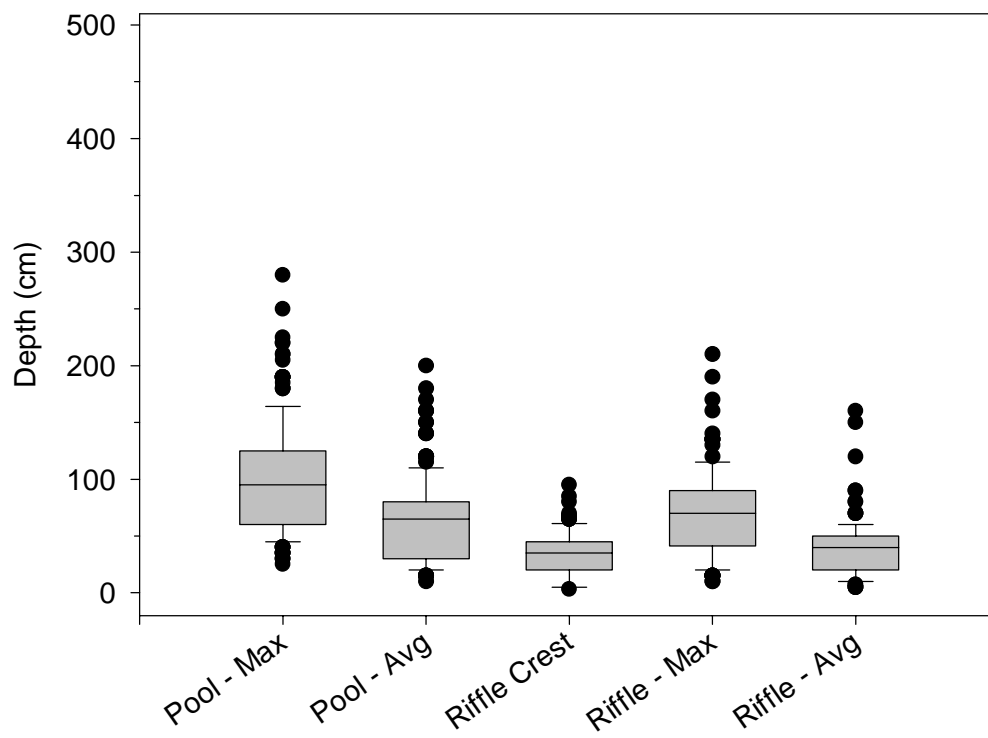
Figure 5. Maximum and average depths for all pools and riffle in the study area of Rio Icacos, February 2001. The top and bottom of the boxes represent the 25th and 75th percentiles, the bar in the center of the box represents the median, whiskers represent the 10th and 90th percentiles, and closed circles represent the entire range of the data.
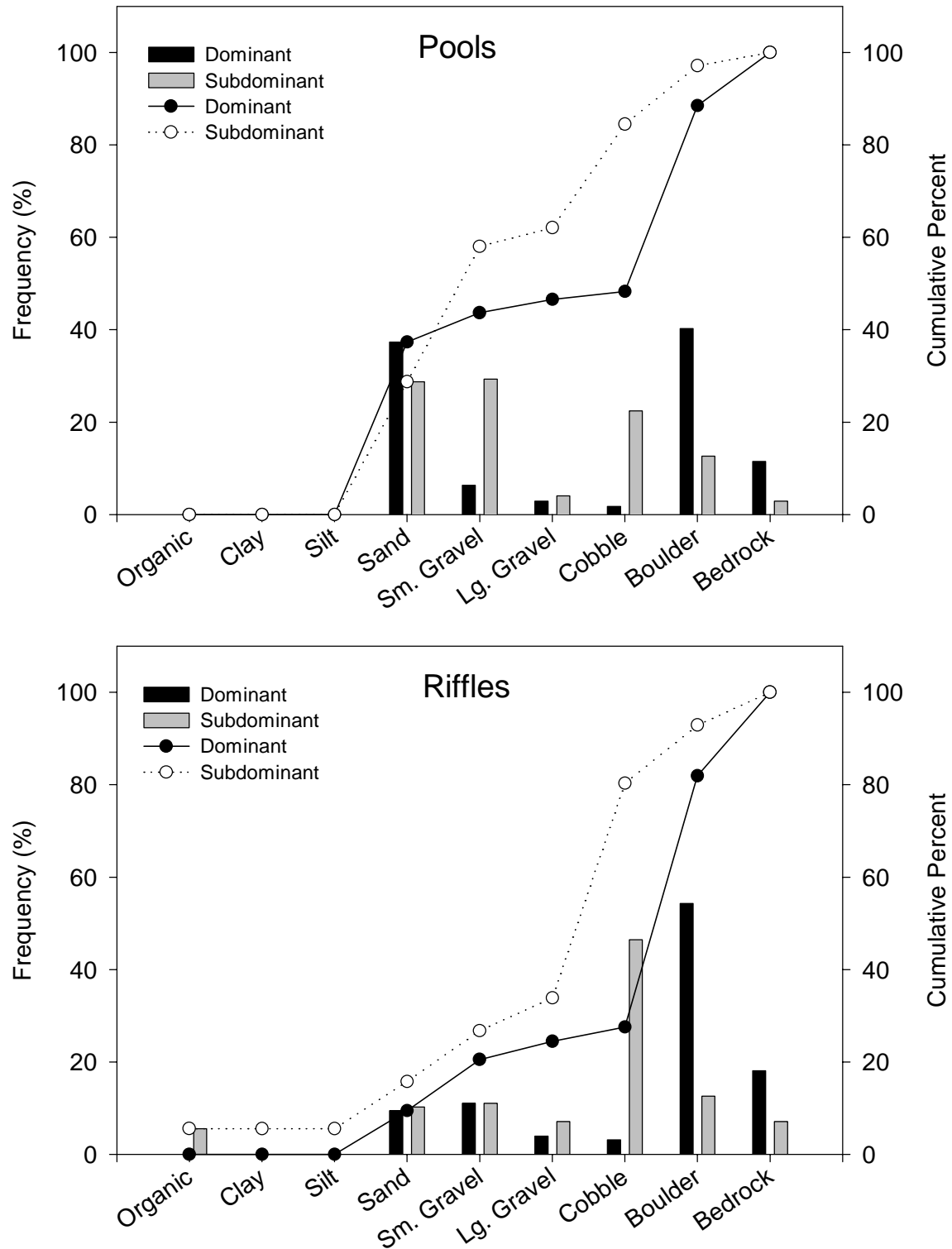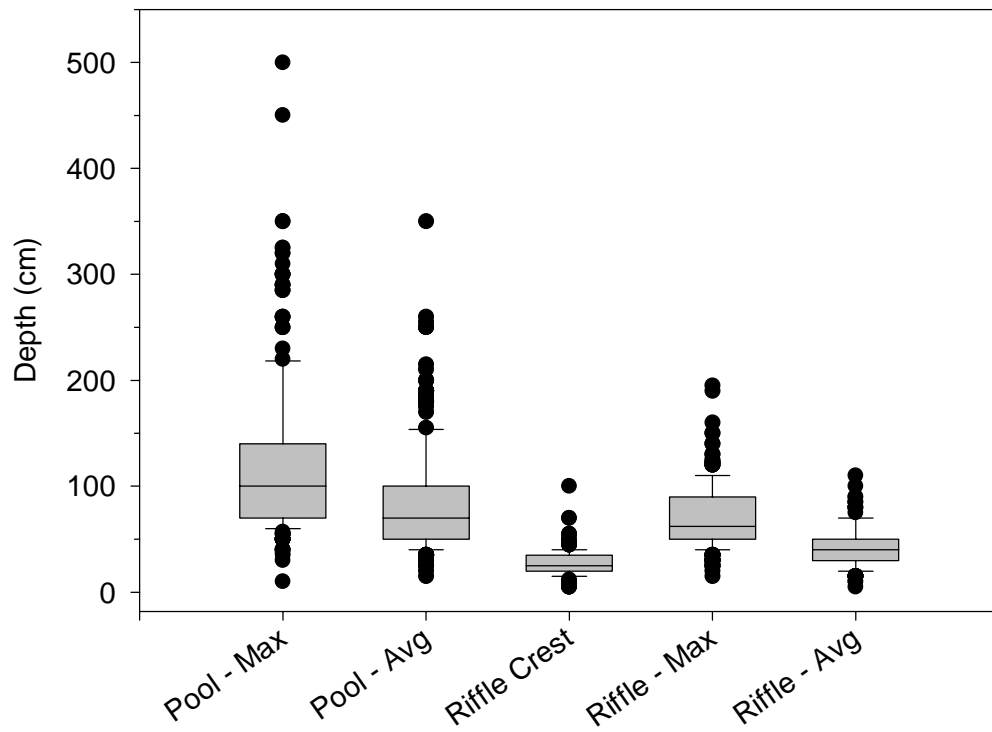
Figure 6. Frequency (percent) and cumulative percent of dominant and subdominant substrate occurrence for all pools and riffles in the study section of Rio Icacos, February 2001.
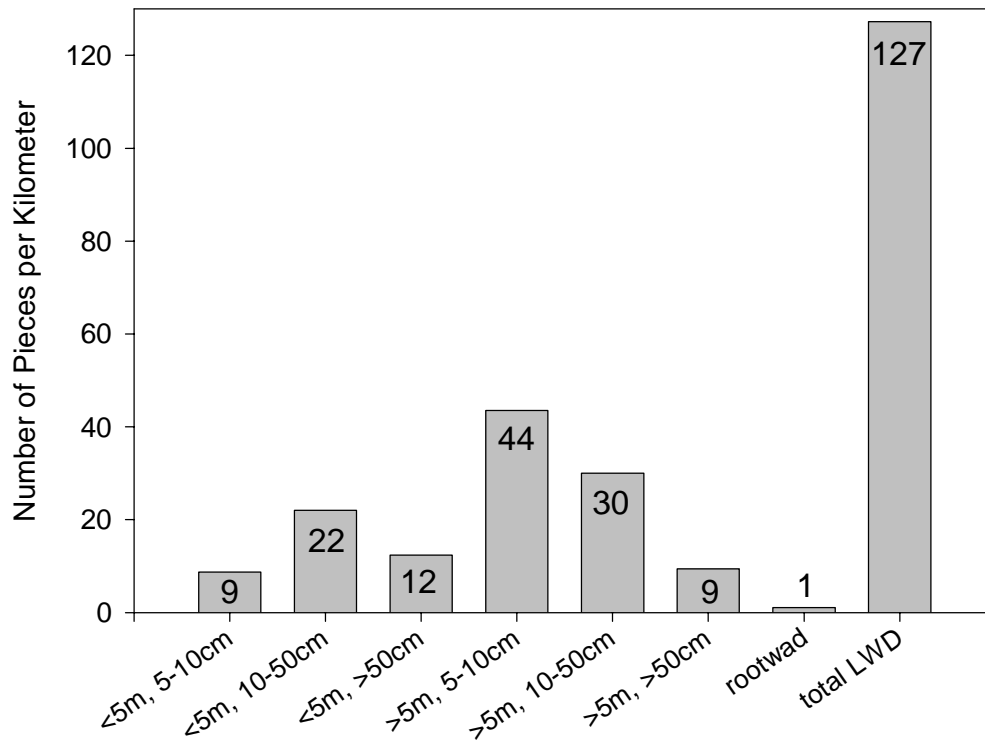
Figure 7. LWD per kilometer in the study reach of Rio Icacos, February 2001. X-axis labels are LWD size classes with the first number indicating length and the second number indicating diameter.
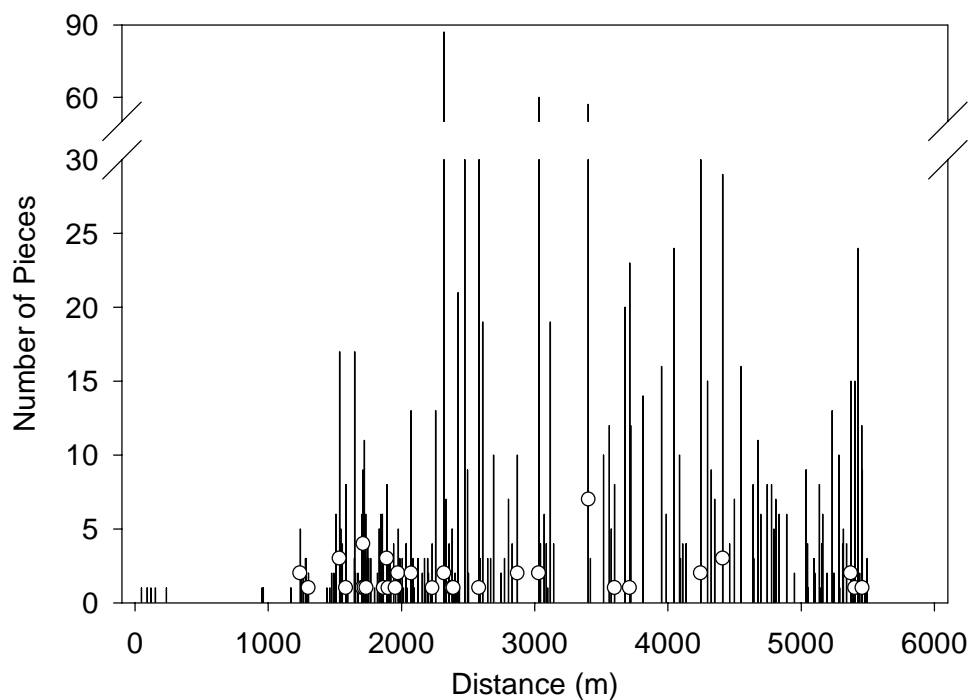


Figure 8. Distribution and abundance of LWD in each habitat unit within the study reach of Rio Icacos. Open circles represent the amount of the total LWD that was >5 m in length, >55 cm in diameter. X-axis indicates distance upstream from confluence with Rio Cubuy.
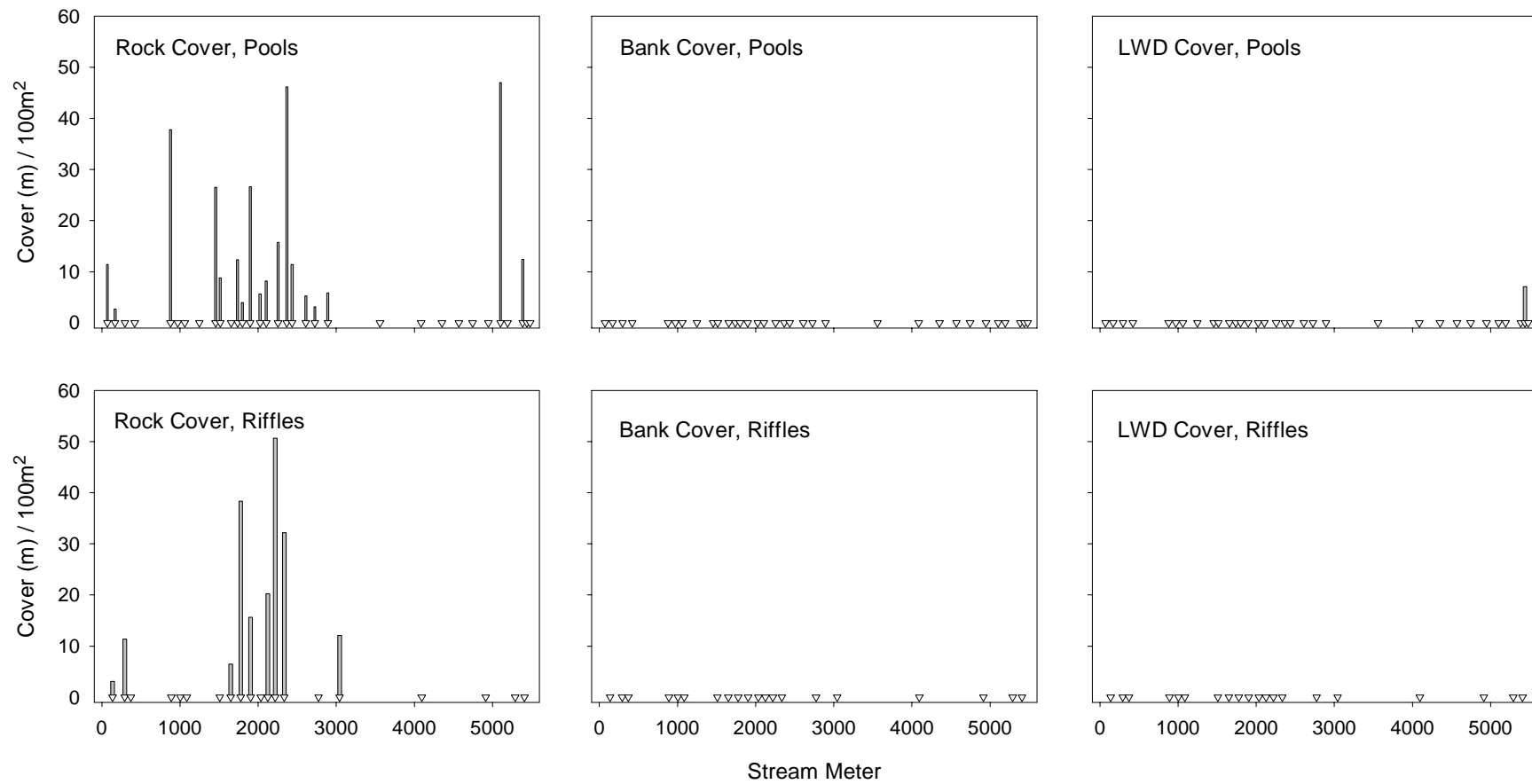
Figure 9. Linear meters of rock, undercut bank, and LWD cover for approximately 20% of pools and riffles in the study reach of Rio Icacos, February 2001. Open triangles indicate locations where cover was estimated. X-axis indicates meters upstream from the confluence with Rio Cubuy. X-axis and y-axis scales are the same for all figures.
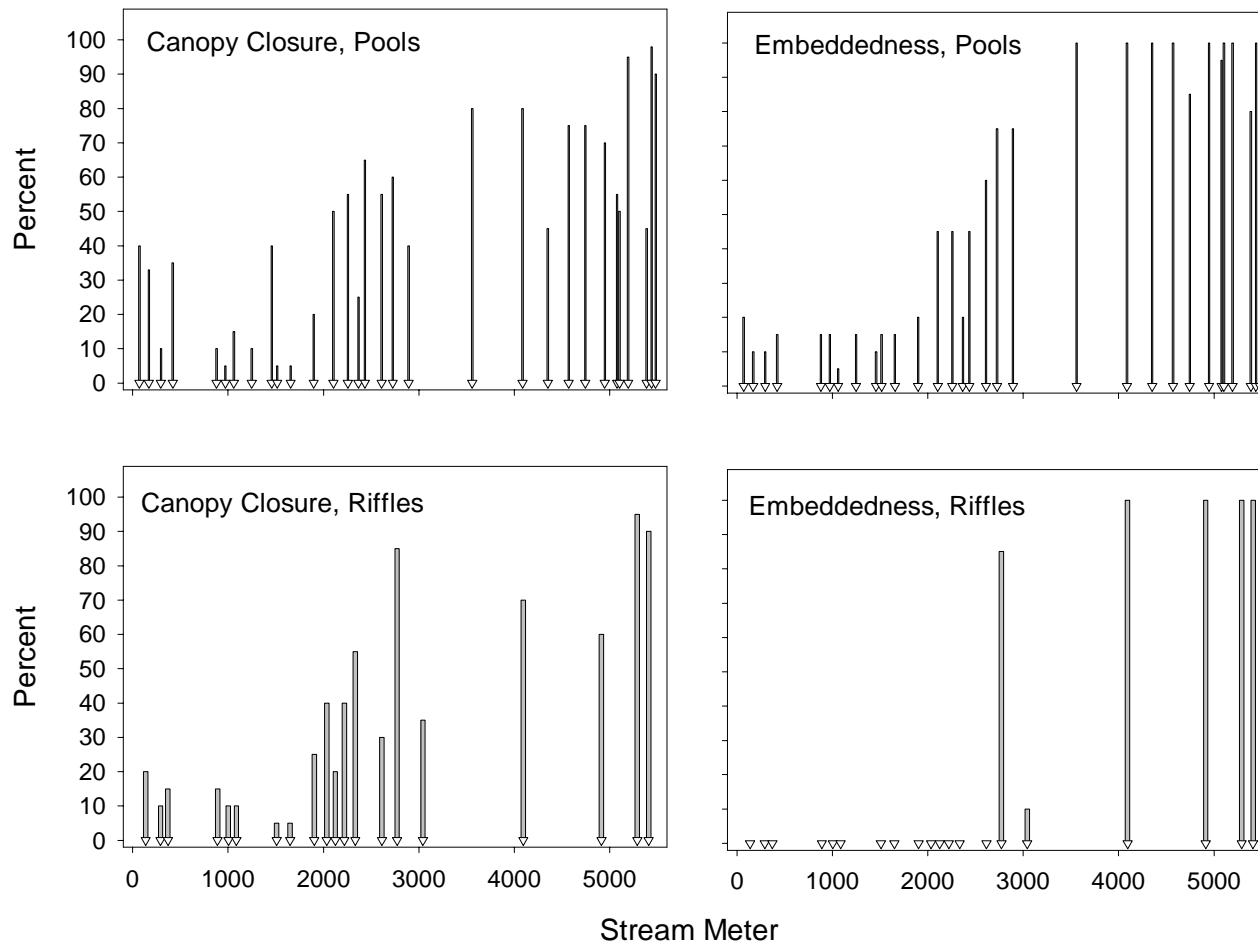
Figure 10. Percent of canopy cover and percent of embedded substrates in approximately 20% of the pools and riffles in the study section of Rio Icacos, February 2001. X-axis indicates the number of meters upstream from the confluence with Rio Cubuy.
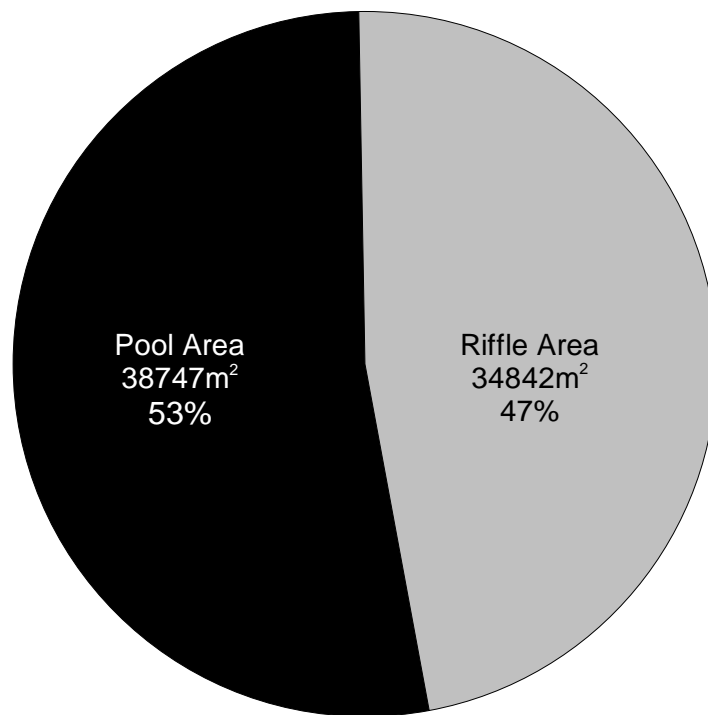
Figure 11. Estimated area of Rio Espiritu Santo in pools and riffles as calculated using BVET techniques, July 2001.



Figure 12. Bankfull and wetted channel widths for Rio Espiritu Santo, July 2001. The left and right of the boxes represent the 25th and 75th percentiles, the bar in the center of the box represents the median, whiskers represent the 10th and 90th percentiles, and closed circles represent the entire range of the data.

Figure 13. Maximum and average depths for all pools and riffle in the study area of Rio Espiritu Santo, July 2001. The top and bottom of the boxes represent the 25th and 75th percentiles, the bar in the center of the box represents the median, whiskers represent the 10th and 90th percentiles, and closed circles represent the entire range of the data.
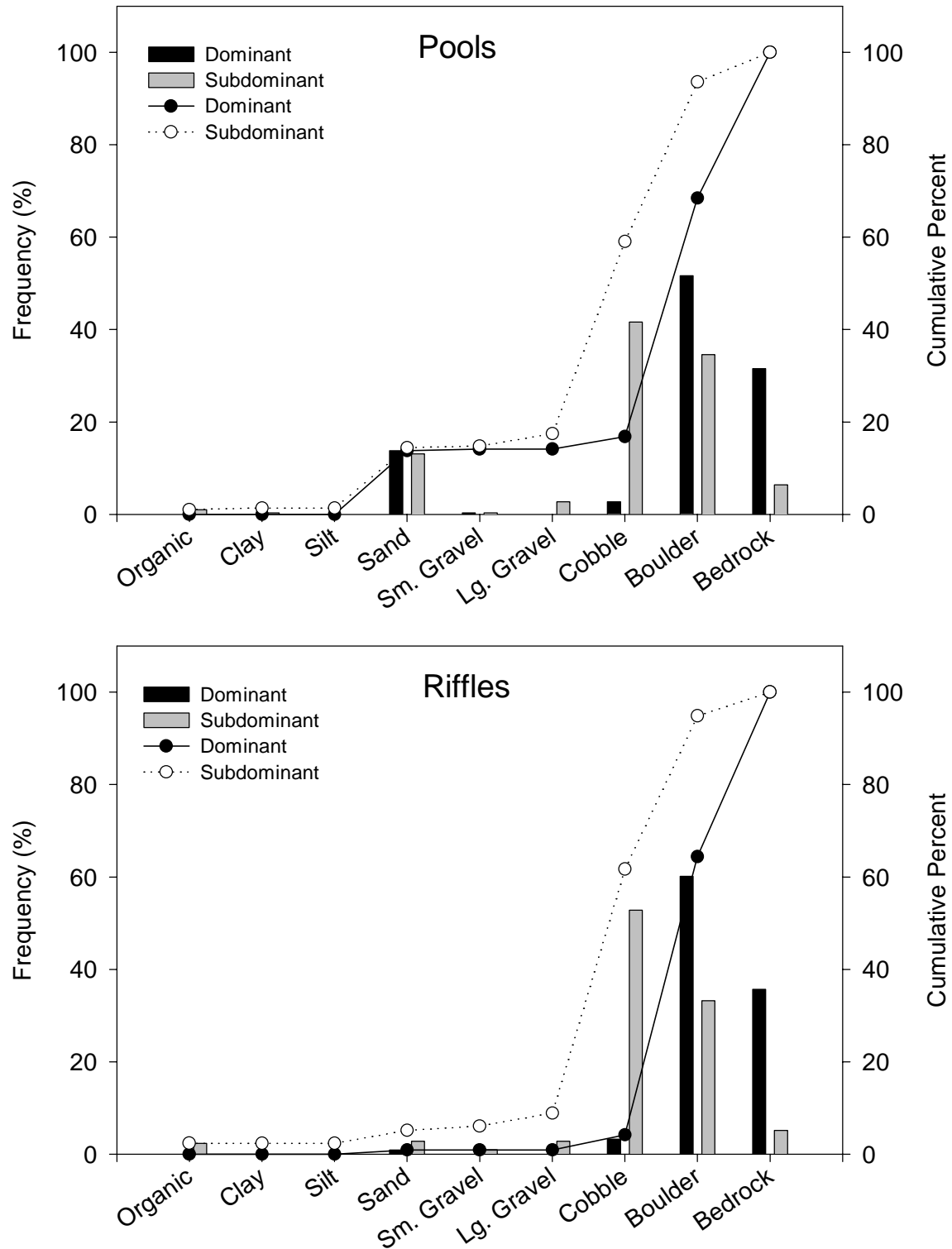
Figure 14. Frequency (percent) and cumulative percent of dominant and subdominant substrate occurrence for all pools and riffles in the study section of Rio Espiritu Santo, July 2001.
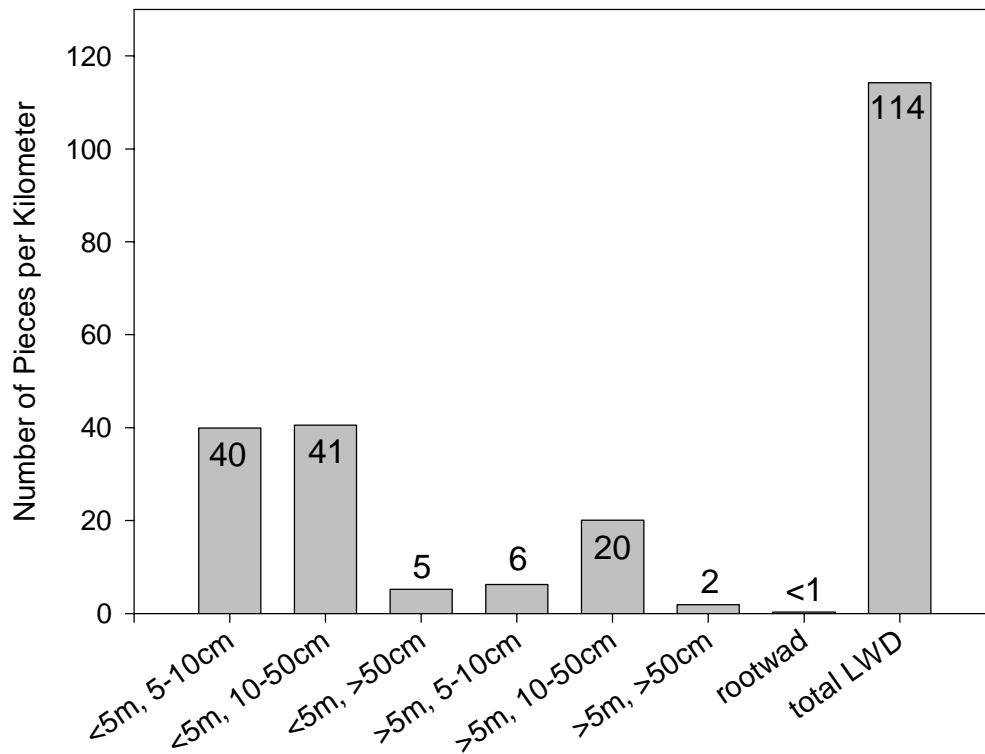
Figure 15. LWD per kilometer in the study reach of Rio Espiritu Santo, July 2001. X-axis labels are LWD size classes with the first number indicating length and the second number indicating diameter.
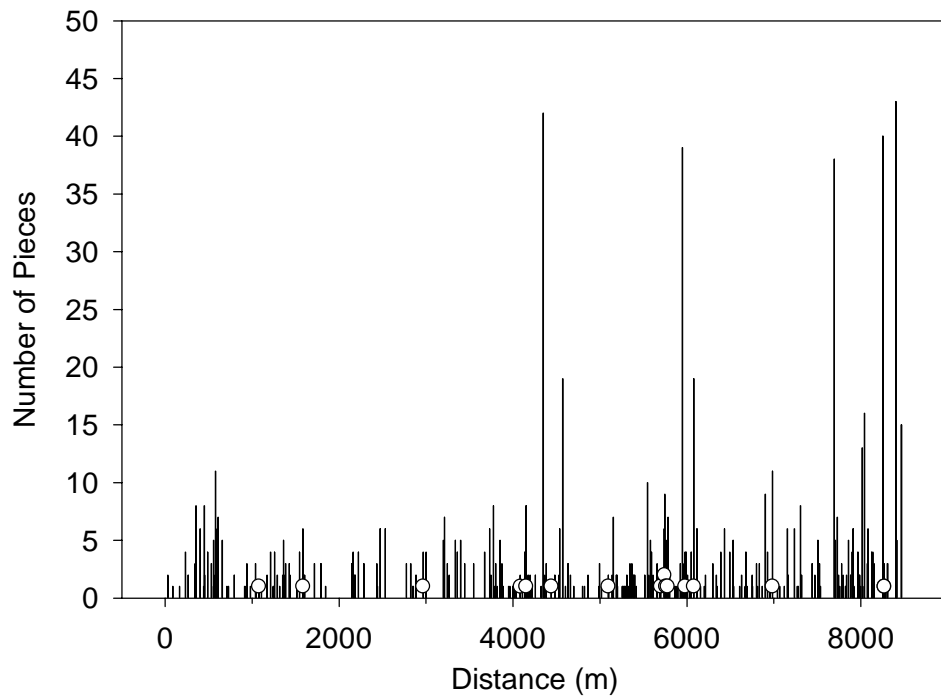


Figure 16. Distribution and abundance of LWD in each habitat unit within the study reach of Rio Espiritu Santo, July 2001. Open circles represent the amount of the total LWD that was >5 m in length, >55 cm in diameter. X-axis indicates distance upstream from Forest boundary.
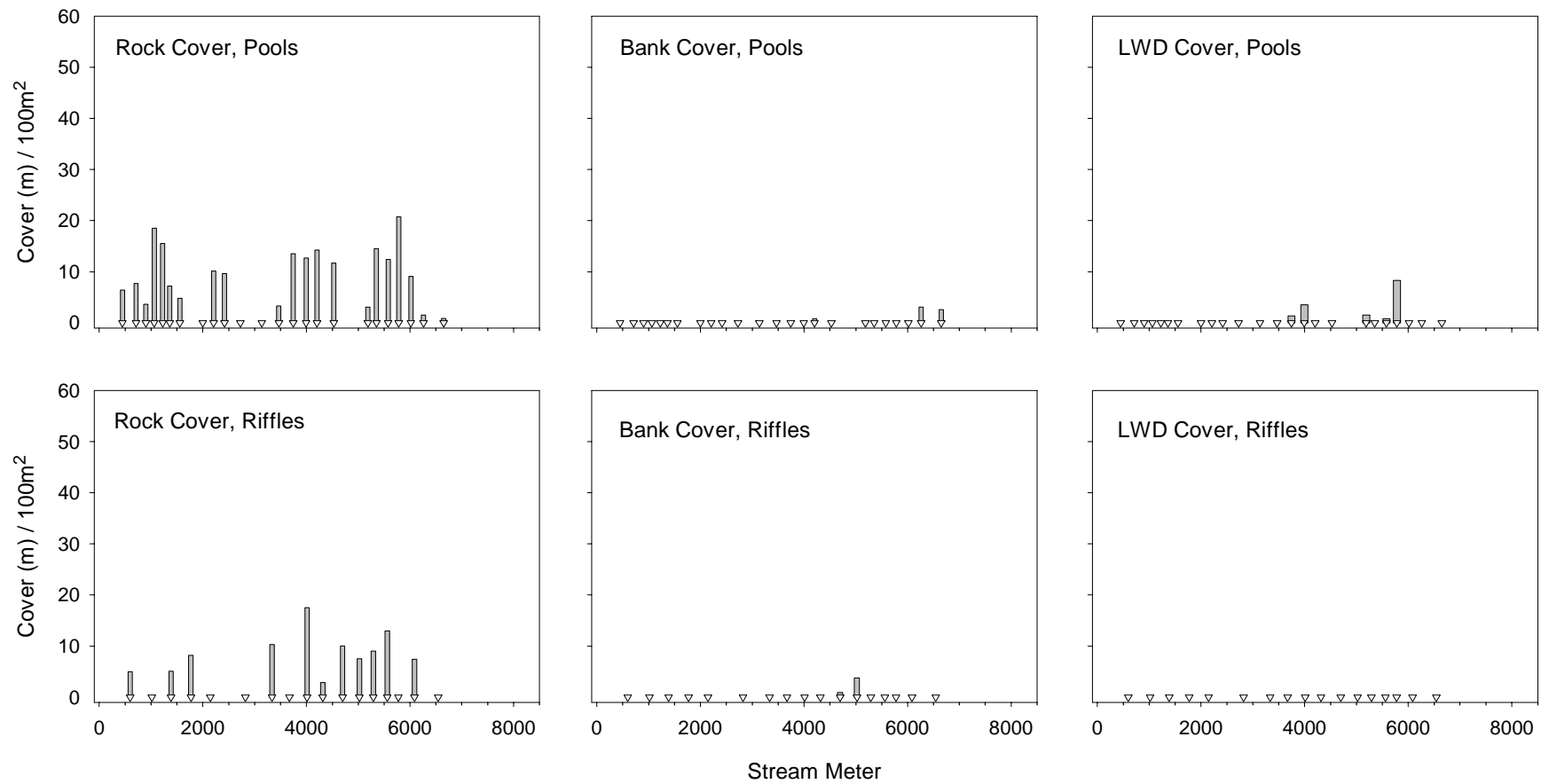
Figure 17. Linear meters of rock, undercut bank, and LWD cover for approximately 20% of pools and riffles in the study reach of Rio Espiritu Santo, July 2001. Open triangles indicate locations where cover was estimated. X-axis indicates meters upstream from Forest boundary. X-axis and y-axis scales are the same for all figures.
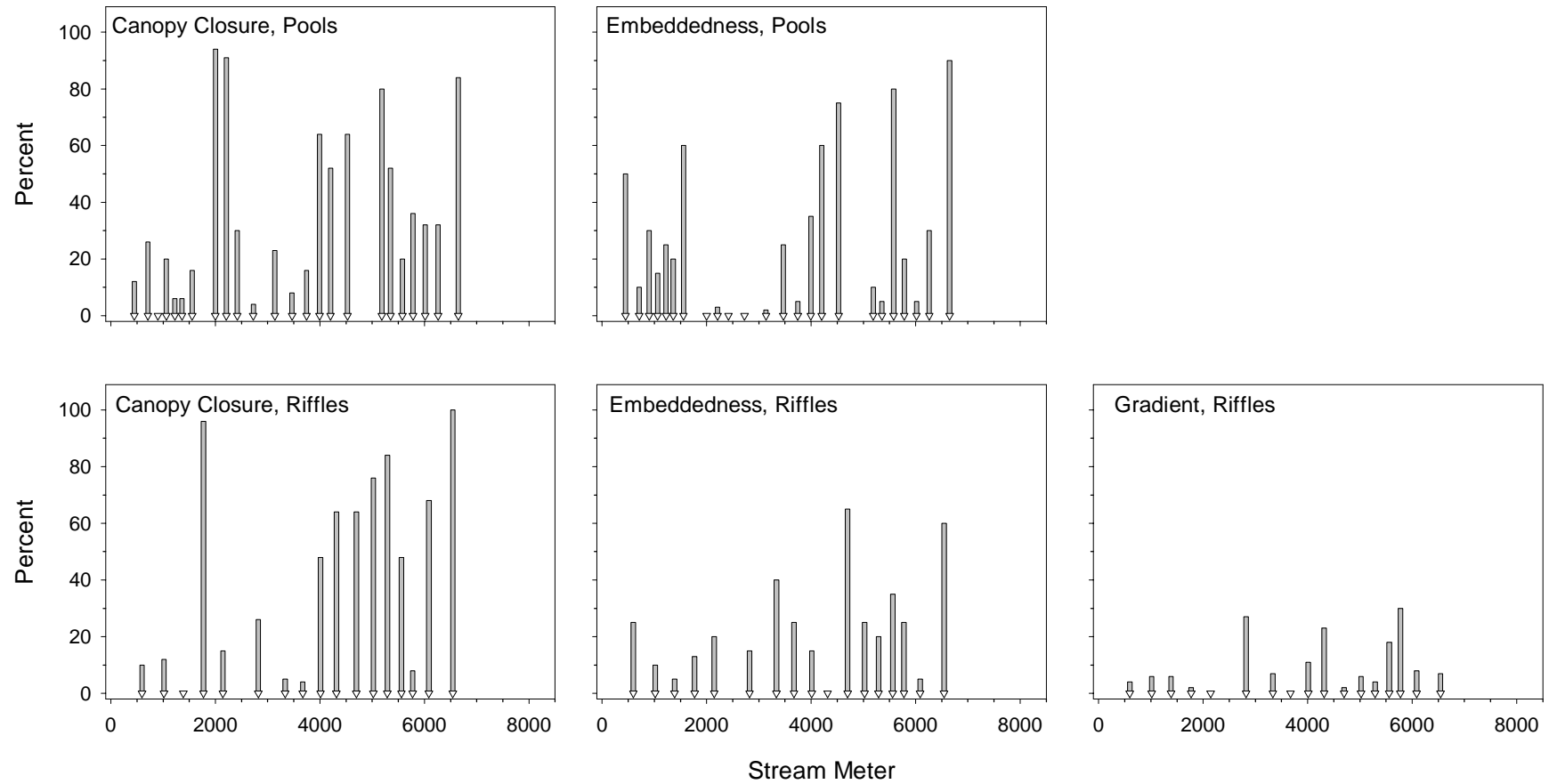
Figure 18. Percent of canopy cover, percent of embedded substrates, and percent gradient in approximately 20% of the pools and riffles in the study section of Rio Espiritu Santo, July 2001. Gradient was only measured in riffles. X-axis indicates the number of meters upstream from Forest boundary. X-axis and y-axis scales are the same for all figures.
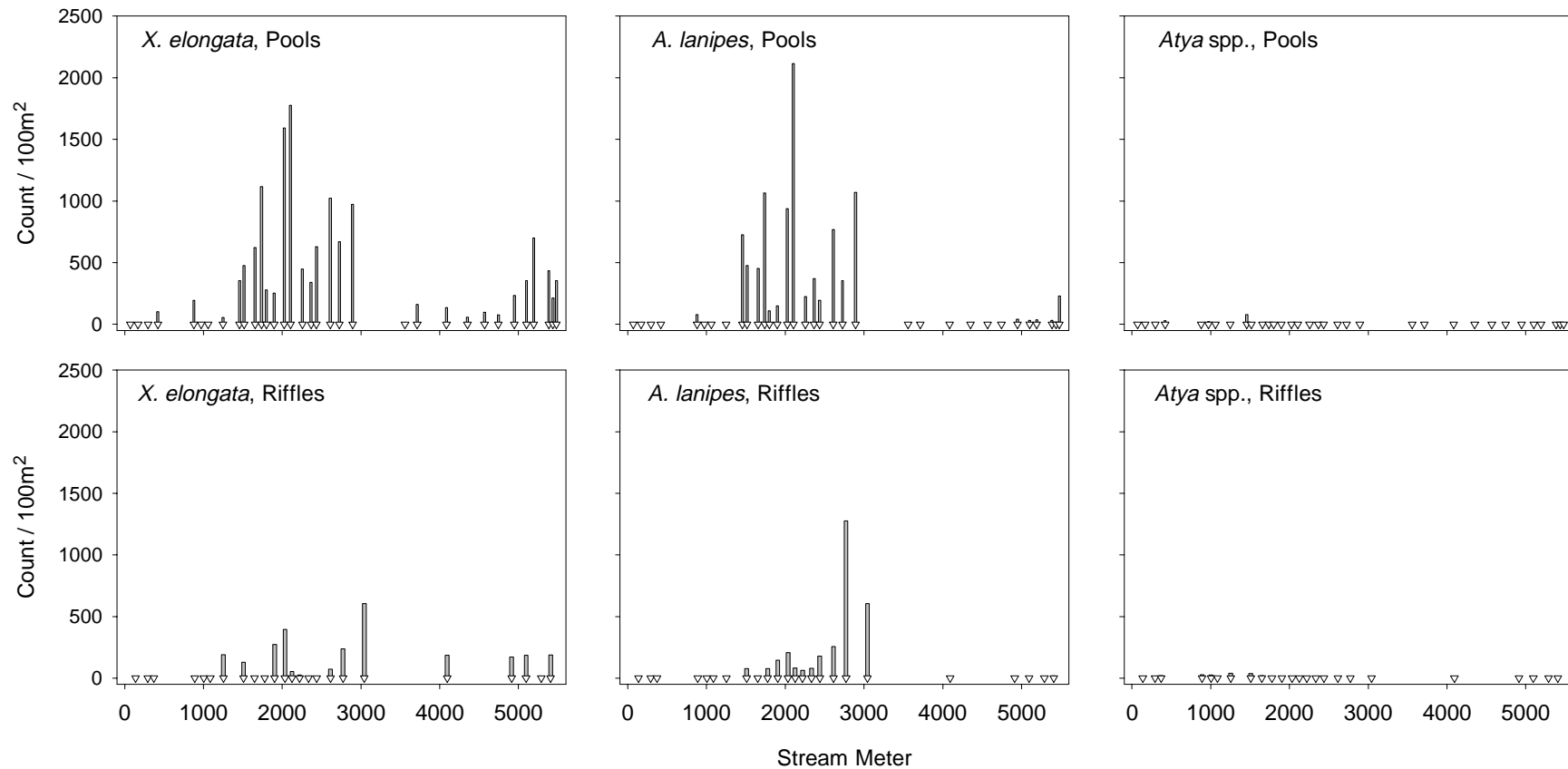
Figure 19. Diver counts of *Xiphocaris elongata*, *Atya lanipes*, and *Atya spp.* per 100 m$^2$ of surface area for approximately 20% of pools and riffles in the study section of Rio Icacos, February 2001. *Atya spp.* consisted of *Atya scabra* and *Atya inocous*, which could not be distinguished by divers. Open triangles indicate locations where diver counts were made. X-axis indicates meters upstream from the confluence with Rio Cubuy. X-axis and y-axis scales are the same for all figures.
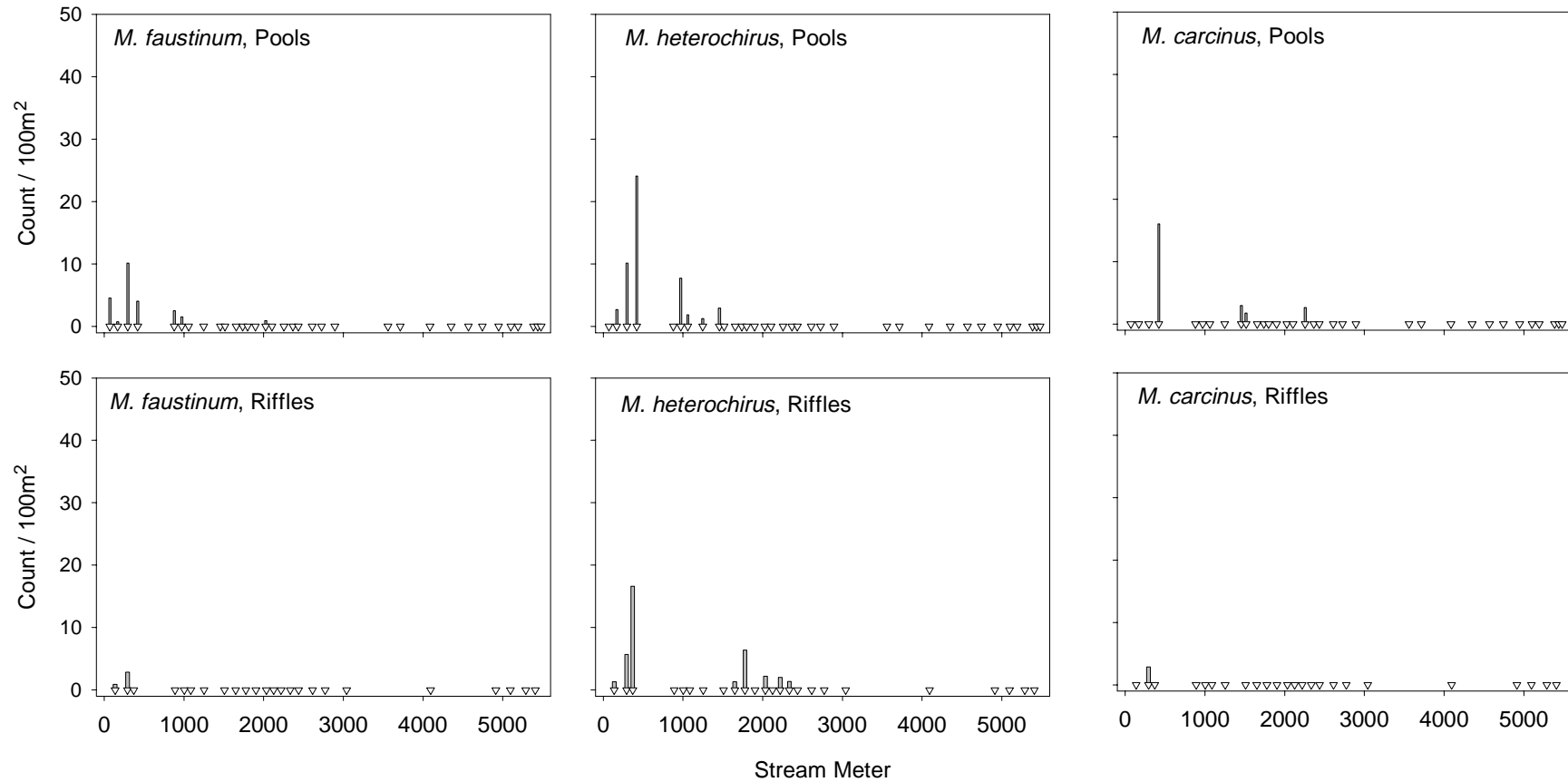
Figure 20. Diver counts of *Macrobrachium faustinum*, *Macrobrachium heterochirus*, and *Macrobrachium carcinus* per 100 m$^2$ of surface area for approximately 20% of pools and riffles in the study section of Rio Icacos, February 2001. Open triangles indicate locations where diver counts were made. X-axis indicates meters upstream from the confluence with Rio Cubuy. X-axis and y-axis scales are the same for all figures.
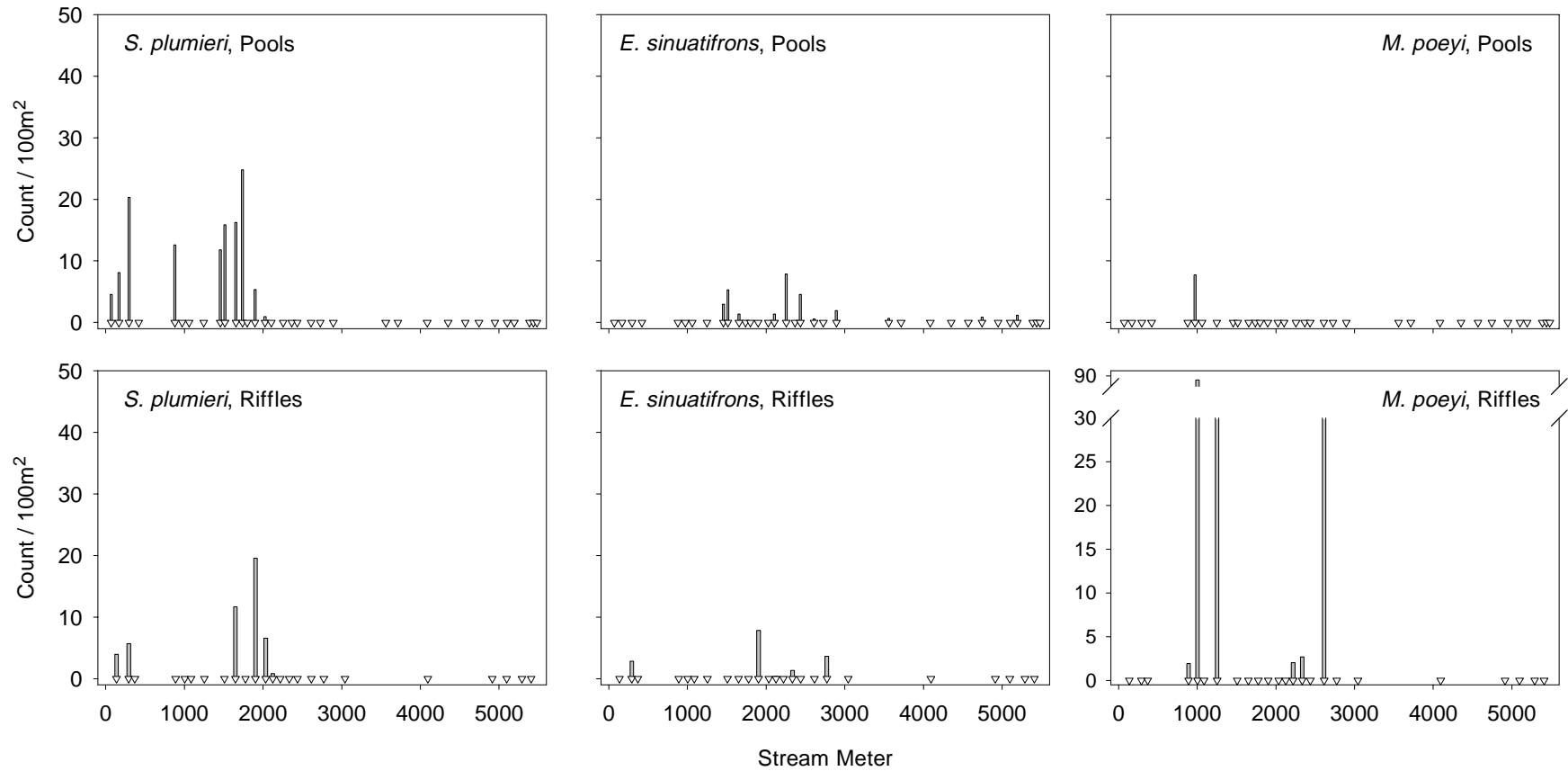
Figure 21. Diver counts of *Micratya poeyi*, *Epilobocera sinuatifrons*, and *Sicydium plumieri* per 100 m$^2$ of surface area for approximately 20% of pools and riffles in the study section of Rio Icacos, February 2001.  Open triangles indicate locations where diver counts were made. X-axis indicates meters upstream from the confluence with Rio Cubuy. X-axis and y-axis scales are the same for all figures except for the x-axis for *M. poeyi* in riffles.
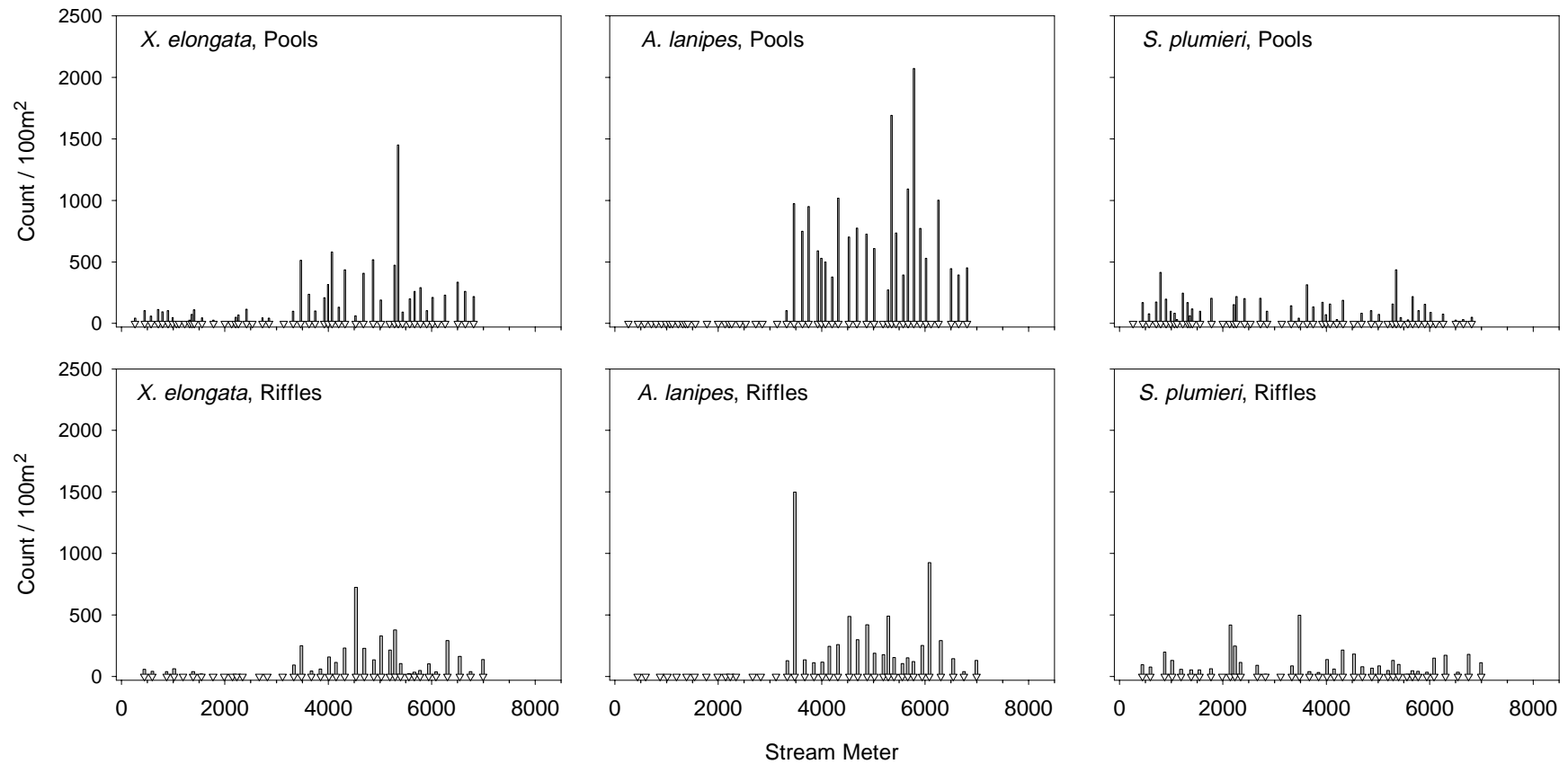
Figure 22. Diver counts of *Xiphocaris elongata*, *Atya lanipes*, and *Sicydium plumieri* per 100 m$^2$ of surface area for approximately 20% of pools and riffles in the study section of Rio Espritu Santo, July 2001.  Open triangles indicate locations where diver counts were made. X-axis indicates meters upstream from the Forest boundary. X-axis and y-axis scales are the same for all figures.
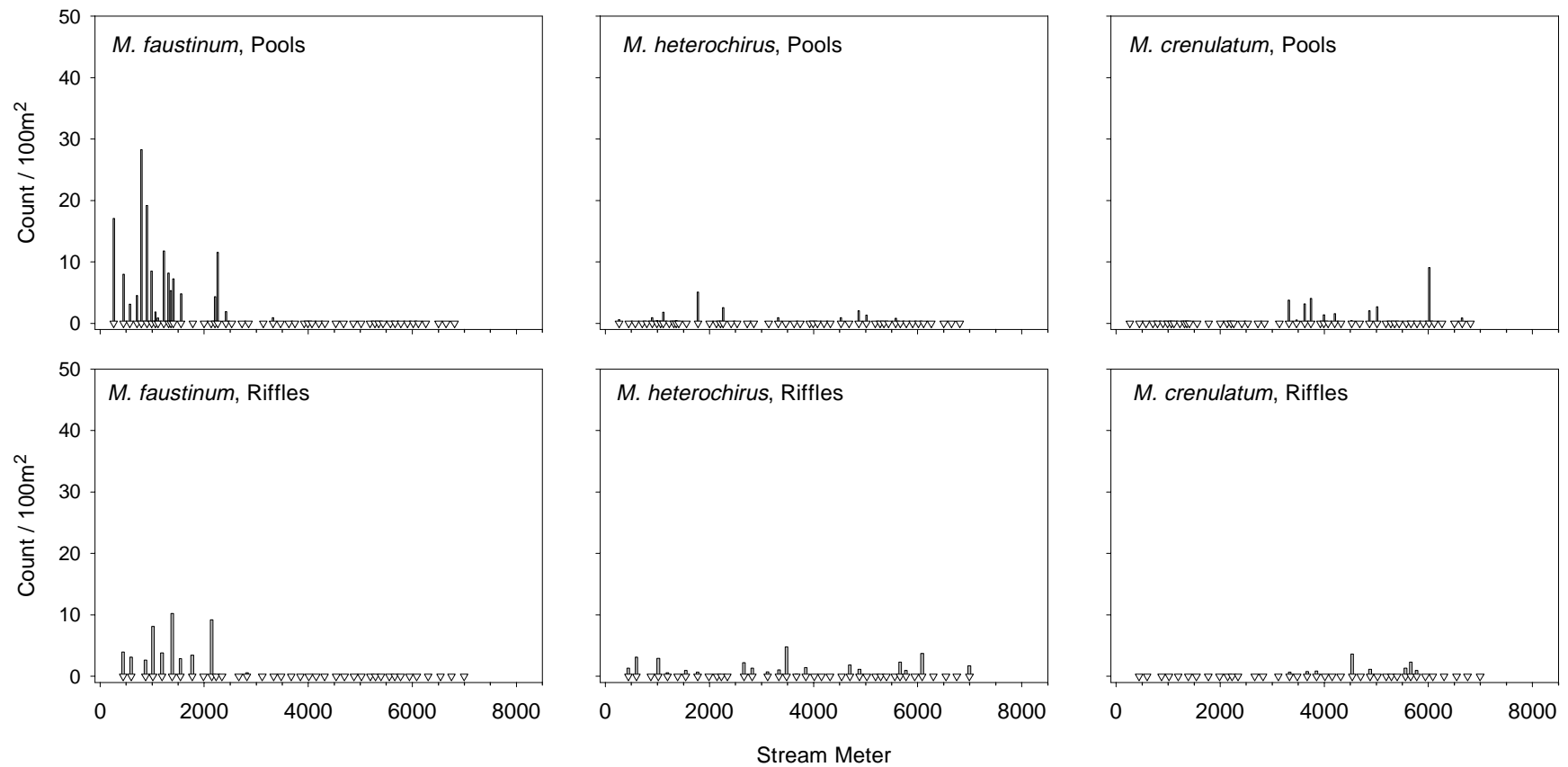
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Figure 23. Diver counts of *Macrobrachium faustinum*, *Macrobrachium heterochirus*, and *Macrobrachium crenulatum* per 100 m$^2$ of surface area for approximately 20% of pools and riffles in the study section of Rio Espiritu Santo, July 2001. Open triangles indicate locations where diver counts were made. X-axis indicates meters upstream from the Forest boundary. X-axis and y-axis scales are the same for all figures.
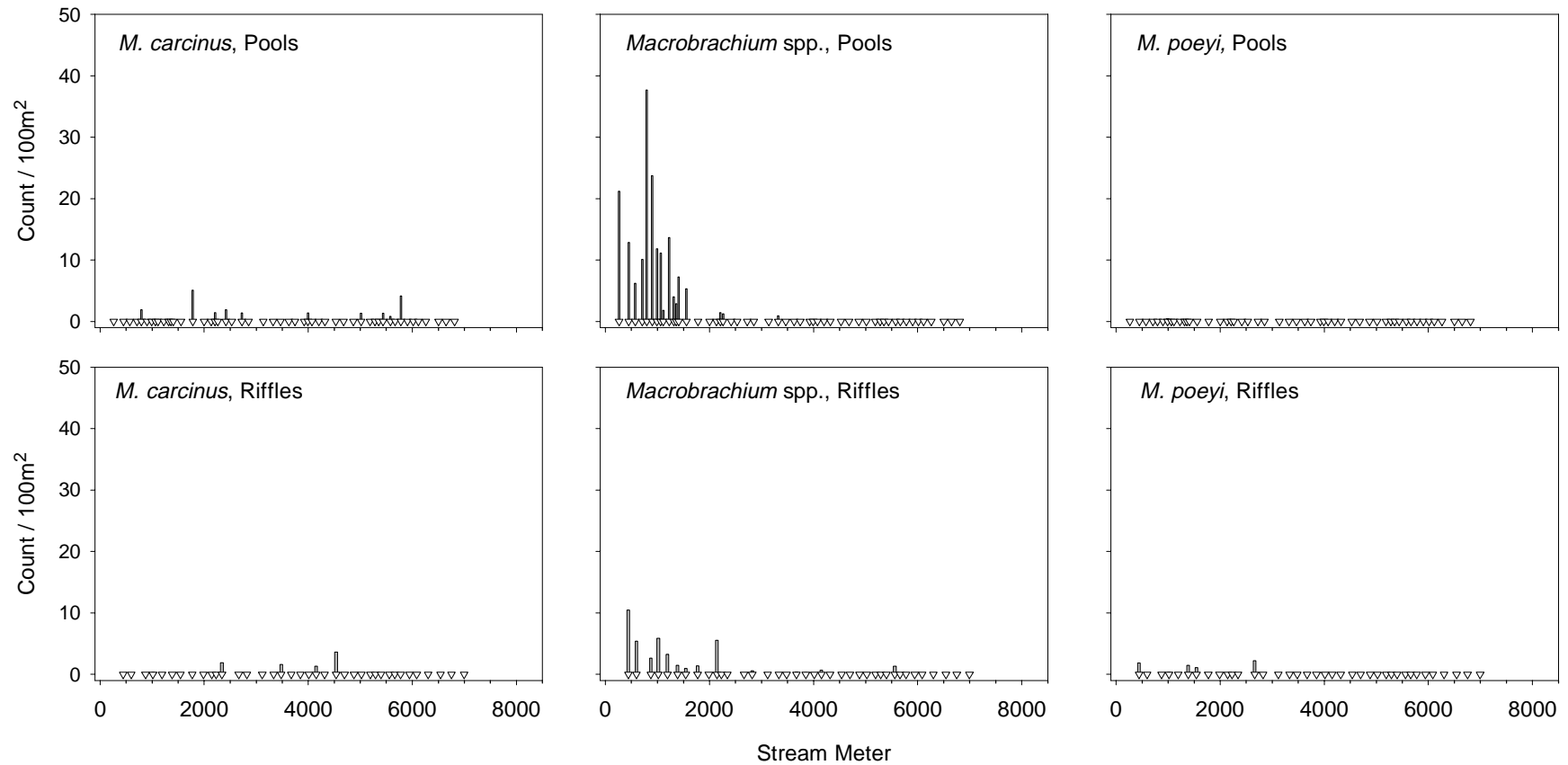
Figure 24. Diver counts of *Macrobrachium carcinus*, *Macrobrachium* spp., and *Micratya poeyi* per 100 m$^2$ of surface area for approximately 20% of pools and riffles in the study section of Rio Espiritu Santo, July 2001. *Macrobrachium* spp consisted of immature *Macrobrachium* that could not be identified by divers. Open triangles indicate locations where diver counts were made. X-axis indicates meters upstream from the Forest boundary. X-axis and y-axis scales are the same for all figures.
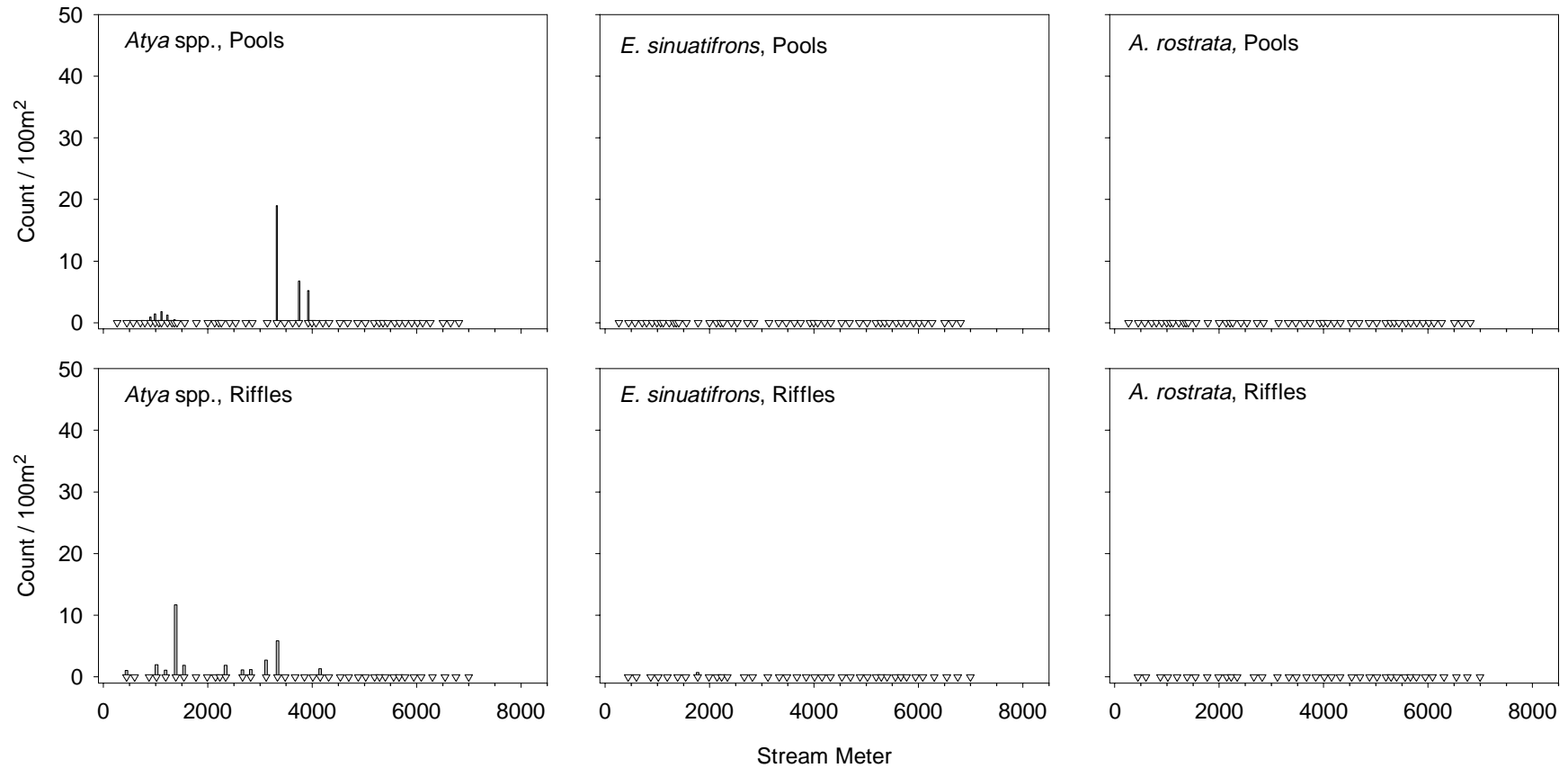
Figure 25. Diver counts of *Atya* spp., *Epilobocera sinuatifrons*, and *Anguilla rostrata* per 100 m$^2$ of surface area for approximately 20% of pools and riffles in the study section of Rio Espiritu Santo, July 2001. *Atya* spp. consisted of *Atya scabra* and *Atya inocous*, which could not be distinguished by divers. *A. rostrata* were not observed within the study section during the diver survey, however they were observed in the first pool downstream of the survey start, and were observed in the survey section during population estimation experiments performed in February 2001. Open triangles indicate locations where diver counts were made. X-axis indicates meters upstream from the Forest boundary. X-axis and y-axis scales are the same for all figures.
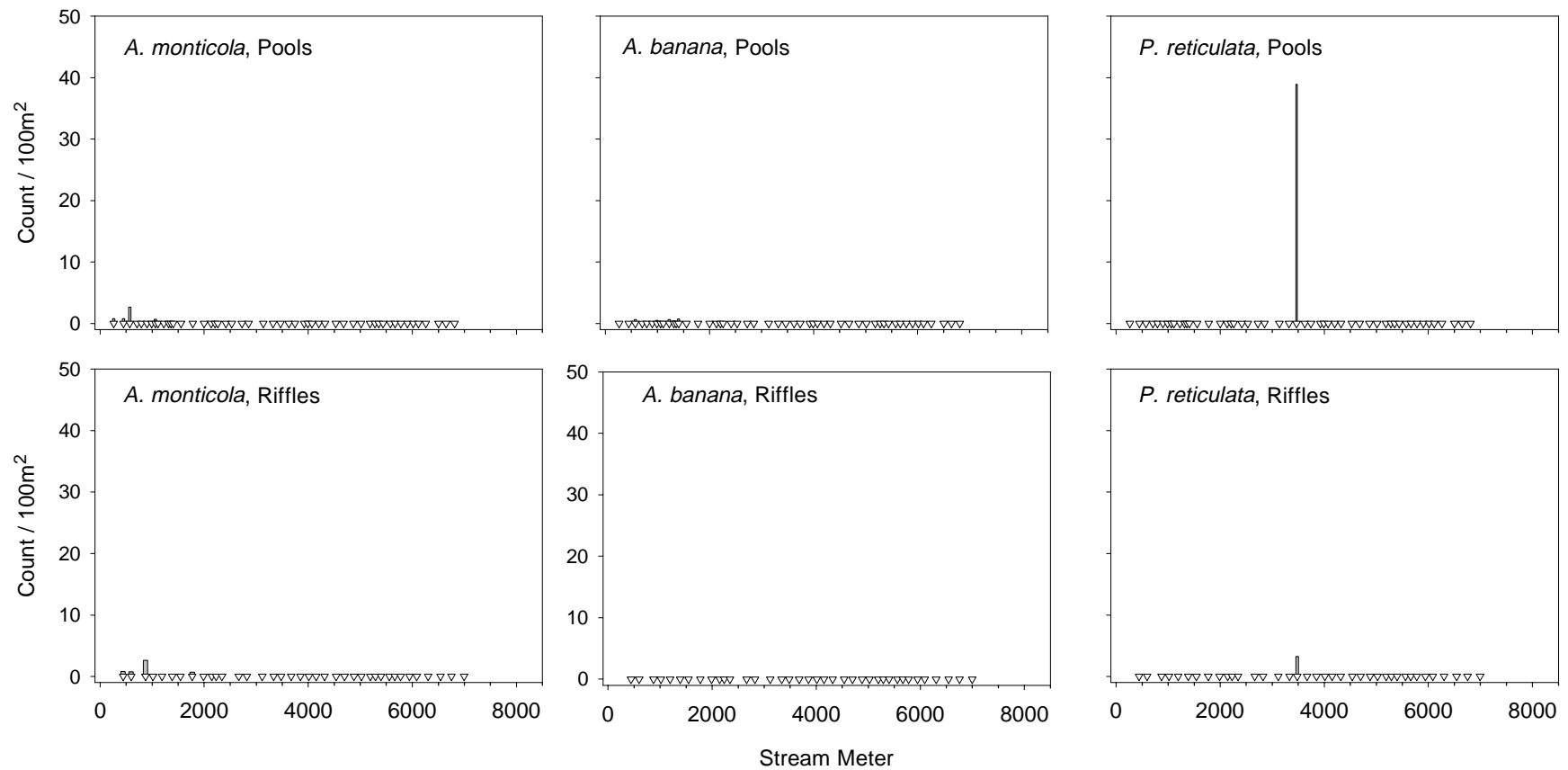
Figure 26. Diver counts of *Agonostomus monticola*, *Awaous banana*, and *Poecilia reticulata* per 100 m$^2$ of surface area for approximately 20% of pools and riffles in the study section of Rio Espiritu Santo, July 2001. Open triangles indicate locations where diver counts were made. X-axis indicates meters upstream from the Forest boundary. X-axis and y-axis scales are the same for all figures.